LIBRARY
DARTMOUTH

JOURNAL OF AGRICULTURAL RESEARCH

VOL. 66 WASHINGTON, D. C., JANUARY 15, 1943 No. 2

EFFECT OF SOIL AND PEAT ADMIXTURES ON THE GROWTH OF PLANTS IN QUARTZ SAND[1]

By PHILIP L. GILE, *senior chemist, Division of Soil and Fertilizer Investigations,* and IRVIN C. FLUSTEL, formerly *associate chemist,*[2] *Division of Soil Chemistry and Physics, Bureau of Plant Industry, Agricultural Research Administration, United States Department of Agriculture*

INTRODUCTION

In a previous publication (*3*)[3] it was shown that millet (*Setaria italica* (L.) Beauv.) does not grow so well in pure quartz sand as in quartz sand to which a little soil is added. Experiments indicated that the beneficial effect of the soil admixture is not due to supplying a trace element, to counteracting an injurious impurity in the sand, to modifying the texture of the sand, or to reducing a total salt injury.

It was suggested that the beneficial effect of the soil is due to its buffer capacity and also to its capacity for supplying available iron. It seemed that the soil admixture should tend to prevent an injurious degree of acidity from developing in the layer immediately contiguous to the roots when the nutrient salts are such that the plant absorbs more cation than anion equivalents. In case the nutrient salts are such that the plant absorbs more anion than cation equivalents, and an alkaline reaction develops, the soil material should reduce the alkalinity and supply available iron.

Since no attempt was made to determine the hydrogen-ion concentration in the water film immediately contiguous to the root, this explanation was not based on data directly determined. The idea was suggested by the results obtained when plants were grown in pure sand with mixtures of salts containing various proportions of nitrate and ammonium salts. As the proportion of ammonium in the fertilizer was increased, the acidity increased, and the yields declined in pure quartz sand but not in the sand-soil mixtures. When all the nitrogen was supplied as nitrate, an alkaline reaction developed in quartz sand, and the plants became chlorotic, owing to a reduced absorption of iron.

Hydrogen-ion determinations made at the end of the growth period on samples representative of all the material in the pot did not always support the conclusion that the soil addition acts beneficially by creating a more favorable hydrogen-ion concentration; since some sand-soil mixtures were more acid than the pure sand cultures. However, it was pointed out that determinations of this character probably do not show the hydrogen-ion concentrations of the absorption films. Since the acidity or alkalinity is developed in the films by the nonequivalent absorption of cations and anions, there should be periods when the hydrogen-ion concentration in the films should be much higher or lower than that obtaining in the medium as a whole.

[1] Received for publication August 6, 1942.

[2] Now senior chemist, Western Regional Research Laboratory, Bureau of Agricultural Chemistry and Engineering, Agricultural Research Administration, U. S. Department of Agriculture.

[3] Italic numbers in parentheses refer to Literature Cited, p. 64.

Since the foregoing explanation was suggested, additional sand-culture experiments have been conducted that throw some light on the beneficial effect of soil admixtures. These experiments are described here.

METHODS

Details regarding the pot experiments were as follows, except as otherwise noted. Glazed earthenware crocks without drainage holes were used as containers. They were of 1-gallon capacity and held approximately 5,000 gm. of quartz sand or sand-soil mixture. Ten millet, or six or seven wheat (*Triticum aestivum* L.), plants were grown per pot for periods that ranged from 25 to 50 days, according to the season. When the millet plants were cut they were in the joint stage or the heads were about to appear. The water content of the sand or sand-soil mixture, determined by weighing, was maintained at 15 percent by the addition of distilled water. The quantity of soil mixed with the sand varied with the colloid content of the soil. Unless specified otherwise, the soil addition was sufficient to supply 50 gm. of colloidal material per pot. The different mixtures of nutrient salts used in the following experiments are shown in table 1. Most data on the effect of soil admixtures were obtained with the standard mixture, No. 3. Nutrient salts, dissolved in 750 cc. of water to bring the sand to a 15-percent water content, were added just before planting. The quartz sand used in the experiments was made up chiefly of particles 1.0 to 0.5 mm. in diameter.

TABLE 1.—*Mixtures of nutrient salts used in sand cultures*

Salt used in nutrient mixture	Amount of salt applied per pot in mixture No.—				
	1	2	3	4	5
	Gram	*Gram*	*Gram*	*Gram*	*Gram*
Potassium nitrate, KNO_3			0.93	0.93	0.499
Ammonium sulfate, $(NH_4)_2SO_4$	0.938		.33		
Ammonium nitrate, NH_4NO_3		0.57		.20	
Calcium nitrate, $Ca(NO_3)_2.4H_2O$					1.103
Potassium sulfate, K_2SO_4		.82			
Potassium chloride, KCl	.685				
Magnesium sulfate, $MgSO_4.7H_2O$				.45	.45
Magnesium chloride, $MgCl_2.6H_2O$	.42	.42	.42		
Monocalcium phosphate, $Ca(H_2PO_4)_2.H_2O$	.36	.36	.36	.36	
Dipotassium phosphate, K_2HPO_4					.25
Monopotassium phosphate, KH_2PO_4					.19
Sodium chloride, NaCl	.05	.05	.05	.05	.05
Ferric tartrate, $Fe_2(C_4H_4O_6)_3.H_2O$	.0185	.0185	.0185	.0185	.0185
Manganese sulfate, $MnSO_4.2H_2O$	.0015	.0015	.0015	.0015	.0015
Boric acid, H_3BO_3	.003	.003	.003	.003	.003
Zinc chloride, $ZnCl_2$	.00013	.00013	.00013	.00013	.00013
Copper sulfate, $CuSO_4.5H_2O$	.00047	.00047	.00047	.00047	.00047

COMPARATIVE YIELDS OF MILLET IN QUARTZ SAND AND IN A SAND-PEAT MIXTURE, AS INFLUENCED BY THE HYDROGEN-ION CONCENTRATION OF THE PEAT

According to the ideas advanced, addition of soil to a quartz sand culture improves growth only through reducing the hydrogen-ion concentration where the nutrient salts are such that acidity is developed. If this is correct, sand-soil mixtures containing nearly neutral soils should exceed the yields of pure sand cultures by greater amounts than sand-soil mixtures containing acid soils of low buffer capacity.

This was true for the most part, although the correlation between the hydrogen-ion concentration of a soil and the magnitude of the increase it produced was by no means close. Probably there would have been a closer correlation if the data for different soils had been obtained in a single experiment instead of in many different experiments, since it was observed that the beneficial effect of a single soil varied considerably in different experiments, owing presumably to different conditions of light, temperature, and humidity.

The following experiment shows that the beneficial effect of the soil admixture may be influenced markedly by the hydrogen-ion concentration of the material. The experiment was conducted with peat, but previous work has shown that peat has the same growth-promoting effect as soil when added to sand cultures. In this experiment the effect of an unlimed moss peat of pH 3.5 was compared with the effects of three lots of the same peat limed some months previously to pH values of 5.0, 5.9, and 6.6. The quantities of calcium hydroxide required to produce these hydrogen-ion concentrations were, respectively, 2.9, 4.3, and 5.3 percent of the weight of peat. Before the peats were mixed with the sand they were ground to pass through a ½-mm. sieve. The nutrient salts applied to the pure sand and the sand-peat mixtures were the standard fertilizer mixture, No. 3 of table 1, used in previous experiments. Millet was grown from April 19 to May 13.

It is evident from the data in table 2 that the effect of peat on growth in sand cultures varied with the degree to which the culture had been neutralized, at least to a limit of about pH 6. If no determinations had been made of the hydrogen-ion concentrations of the cultures before and after growth, it would have seemed obvious that the effect of peat on growth in sand cultures lies in its effect on the hydrogen-ion concentration of the medium. However, the fact that the pure sand cultures before and after growth had the same pH values as the superior culture containing the peat of pH 5.9 seems to indicate that the beneficial effect of the peat does not lie in modifying the hydrogen-ion concentration of the medium.

TABLE 2.—*Effects of peats having different hydrogen-ion concentrations on the yield of millet in quartz sand*

Peat mixed with the sand		Air-dry yield of individual pots				Average air-dry yield per pot	Hydrogen-ion concentration of medium	
Amount (grams)	pH						At start of experiment	At end of experiment
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*pH*	*pH*
0		5.12	4.06	4.42	4.07	4.42	6.3	5.6
5	3.5	2.50	2.80	4.44	3.70	3.36	5.3	4.4
10	3.5	2.28	3.27	1.58	1.80	2.23	4.6	
20	3.5	1.35	1.13	1.32	.96	1.19	4.4	
40	3.5	.46	.68	.48	.73	.59	4.2	4.4
5	5.0	5.78	5.62	5.15	6.23	5.70	5.9	5.0
10	5.0	5.43	5.82	6.15	5.76	5.79	5.7	
20	5.0	5.82	5.87	5.84	5.79	5.83	5.7	
40	5.0	5.79	5.56	5.29	5.47	5.53	5.7	5.0
5	5.9	6.50	6.58	6.73	6.65	6.62	6.3	5.4
10	5.9	6.98	6.52	6.60	7.02	6.78	6.0	
20	5.9	7.48	6.79	6.85	7.17	7.07	6.0	
40	5.9	6.73	6.32	6.92	7.23	6.80	6.0	5.7
5	6.6	6.00	6.10	6.88	5.70	6.17	6.3	5.4
10	6.6	6.34	6.83	5.88	5.99	6.26	6.6	
20	6.6	6.79	6.70	7.23	7.34	7.02	6.6	
40	6.6	6.93	7.00	6.98	6.21	6.78	6.6	6.1

Similarly contradictory evidence regarding the hydrogen-ion concentration as a factor in the increased growth produced by soil admixtures was obtained in previous work (*3*) with some of the 60 different soils used. This contradiction is disposed of in the explanation outlined in the introduction, on the grounds that the pH values determined at the end of an experiment indicate only the net acidity developed and do not show the acidity or alkalinity obtaining at different times in films contiguous to the roots.

Direct confirmation of the idea that the sand near the roots is different in reaction from the sand in the whole pot was obtained in the experiment with wheat. (See table 9.) After the sand in the whole pot had been sampled, the roots were removed and colorimetric determinations were made of the sand that adhered closely to the roots. This was done by dropping the indicator on a mass of roots and adhering sand. The results are shown in table 3.

TABLE 3.—*Hydrogen-ion concentration of all the sand in a pot and of sand adhering to wheat roots*

Nutrient salt mixture		Hydrogen-ion concentration of—	
No.	Form of nitrogen present	All the sand in a pot	Sand adhering to different lots of roots
		pH	*pH*
1	All as NH_4	4.4	4.2, 4.0
2	½ as NH_4	4.7	4.0, 5.0, 4.2, 4.7
3	⅓ as NH_4	5.2	6.4, 7.6, 8.4, 7.8
4	⅙ as NH_4	6.8	7.5, 8.8
5	All as NO_3	8.6	9.0, 9.2, 8.6

It will be seen that the sand near the roots was in most instances considerably more acid or alkaline than the average sample of the whole pot. Presumably, the microscopic film immediately contiguous to the roots differs from the average sample still more widely in reaction.

The hydrogen-ion determinations made on samples from pots receiving the No. 3 salt mixture are of especial interest. Evidently, here the plants had absorbed most of the ammonia and at the time of examination were drawing more heavily on the nitrates, so that the acidity previously developed was being reduced. Subsequent experiments with wheat and millet indicated that this was the case. A number of pots containing quartz sand and the No. 3 or No. 2 mixture of salts were planted at the same time and harvested at intervals for hydrogen-ion determinations of all the sand in the pot and of sand adhering to roots of the plants. Wheat was grown from December 16 to January 26 and millet from January 26 to March 2. The results are given in table 4.

Column 6 of table 4 gives the pH value for only the greater part of the sand adhering to the roots in a pot. Frequently the sand adhering to individual roots and to certain parts of the same root was ½ to 1 pH unit more acid or alkaline than this "majority" value. Unplanted pots had the same hydrogen-ion concentration at the end of the experiment as at the start.

TABLE 4.—*Hydrogen-ion concentrations developed by wheat and millet at different stages of growth*

Crop	Form of nitrogen present in salt mixtures	Age of plant	Air-dry weight of plants per pot	Hydrogen-ion concentration of—	
				All the sand in a pot	Most sand adhering to roots
		Days	*Grams*	*pH*	*pH*
Wheat	⅓ as NH_4; ⅔ as NO_3	6		6.5	4.8
		21	0.84	6.5	6.3
		27	.87	6.8	7.5
		34	2.19	6.9	7.2
		41	3.35	7.0	7.6
Millet	⅓ as NH_4; ⅔ as NO_3	11	.04	6.9	4.2
		16	.12	6.7	3.9
		21	.47	6.4	4.6
		24	.67	6.2	5.9
		28	1.61	6.3	6.4
		32	3.13	6.5	6.2
		35	5.80	6.3	6.1
Do	½ as NH_4; ½ as NO_3	11	.03	6.9	4.2
		16	.10	6.7	3.9
		21	.36	6.4	4.6
		24	.59	6.2	4.8
		28	1.23	5.9	4.6
		32	2.25	4.8	4.8
		35	4.31	4.8	4.8

From the data in tables 3 and 4 it is concluded (1) that the sand close to the roots may have a hydrogen-ion concentration quite different from that of the whole mass of sand; (2) that the final hydrogen-ion concentration varies with the proportion of nitrate nitrogen to ammonium nitrogen; (3) that when certain proportions of ammonium and nitrate are supplied the hydrogen-ion concentration of the sand, especially that near the roots, varies with the growth of the plant, sometimes shifting from acid to alkaline.

These conclusions are supported by some previous work. Solberg (*8*) found that in quartz sand cultures the sand near the roots was about one-half of a pH unit more acid than sand between roots when nitrogen was supplied as ammonium and one-half of a pH unit more alkaline when nitrogen was supplied as nitrate. These differences are less than those recorded for millet in table 4, but the samples compared are not the same in the two cases. Nightingale (*7*) found that the hydrogen-ion concentration at the surface of apple roots sometimes differed from that of the culture solution by 1 to 2 pH units. The markedly different hydrogen-ion concentrations developed with different proportions of ammonium and nitrate nitrogen (table 3) are in general accord with the data obtained by Trelease and Trelease (*10*) on wheat grown in water cultures containing different proportions of potassium nitrate and ammonium sulfate. The hydrogen-ion concentrations did not vary so widely in the Treleases' culture solutions as in the sand cultures shown in tables 3 and 4, but this difference is probably due to the fact that the water cultures were renewed every 8 days.

Data in table 4, showing a change in reaction from acid to alkaline during the growth period, find only slight confirmation in the Treleases' water-culture data. In their work a reversal in the trend of hydrogen-ion development is shown only by the solution containing 5 parts of ammonium to 95 parts of nitrate, which was tested each

day for the last 8-day period. Probably a similar reversal would have been shown by solutions containing a higher proportion of ammonium if the plants had been grown for a longer time in the same solution. With buckwheat grown in a culture solution containing equal proportions of ammonium and nitrate, Stahl and Shive (*9*) observed a pronounced shift from ammonium to nitrate absorption after blossoming. A change conditioned by maturity of the plant, however, would not account for the shift observed in the present studies, since it does not occur in the series grown with one-half of the nitrogen as ammonium and one-half as nitrate. Moreover, the oldest plants were cut when the heads were just starting to emerge.

EFFECT OF CALCIUM CARBONATE AND INCREASED IRON ON YIELD OF MILLET IN QUARTZ SAND

If the poor growth in pure sand with the standard salt mixture is due to acidity resulting from the absorption of more cation than anion equivalents, it might seem possible to correct the condition by an application of calcium carbonate. However, too much calcium carbonate reduces the availability of iron in the quartz sand cultures to such an extent that the plants become chlorotic. The chlorosis can be overcome to some extent by increasing the iron supply, but too much reactive iron reduces the availability of the phosphate until it becomes deficient. Increasing the phosphate in order to maintain an adequate supply tends to lower the availability of the iron. Because of these conditions it may not be possible to produce optimum conditions for growth merely by adding calcium carbonate to the sand cultures.

In the following experiment the standard mixture of nutrient salts, No. 3, was used. The quantity of precipitated calcium carbonate added to the sand cultures was only 0.5 gm. per pot, since previous work (*2*) had shown that 0.8 gm. induced chlorosis. Three quantities of ferric tartrate were tested in conjunction with this application. There were also several other treatments in this experiment. Additional increments of iron were tried with the all-nitrate mixture of salts, No. 5, since diminished growth with these salts in quartz sand was found to be due to a lack of available iron (*3*). In addition to the potassium in the standard salt mixture, potassium chloride was added to some pots, since it was thought possible that the injurious effect of the acidity developed from these salts might lie in diminishing potassium assimilation, as held by Wadleigh and Shive (*11*). If this were the case, increasing the potassium concentration might ameliorate the condition. The treatment with peat of pH 5.0 was installed as a check on the efficacy of the other treatments. In the previous experiment this peat increased the yield markedly. Millet was grown from May 12 to June 4. The results of the experiment are given in table 5.

The increase produced by calcium carbonate with the highest iron application is almost as large as the increase produced by the peat of pH 5.0, and this in turn is about equal to the average increase produced by 46 different soils in 66 comparisons (*3, p. 620*). The results, therefore, support the idea that the beneficial effect of a soil application lies in acting as a buffer and in supplying available iron.

TABLE 5.—*Effect of calcium carbonate, extra iron, and extra potassium on yield of millet in quartz sand*

Substance added to quartz sand			Air-dry yield of individual pots				Average air-dry yield per pot	Relative yield	pH at end of experiment
Nutrient salt mixture[1] No.	Additional compound								
	Name	Amount							
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Percent*	
3	None		3.82	3.40	4.78	4.04	4.38	100	5.9
3	do		4.92	4.76	4.53	4.79			
3	Calcium carbonate	0.5	4.06	5.98	5.00	5.09	5.03	115	7.5
3	do Iron	.5 .037	3.51	5.21	6.78	6.07	5.39	123	7.5
3	Calcium carbonate Iron	.5 .148	6.80	5.35	6.68	6.10	6.23	142	7.5
3	Potassium chloride	.343	4.11	4.72	4.99	4.15	4.49	103	5.2
3	do	.686	3.52	4.05	4.14	3.87	3.90	89	6.5
3	do	1.029	3.94	3.68	4.10	3.58	3.83	87	6.5
3	Peat, pH 5.0	10	6.40	6.68	6.30		6.46	147	4.7
3	Peat Potassium chloride	10 .343	6.00	5.82	5.45	5.62	5.72	131	4.7
5	None		3.31	4.54	3.91	2.60	3.59	82	7.8
5	Iron	.037	5.18	5.15	4.25	4.25	4.71	108	7.5
5	do	.148	4.19	4.41	4.62	3.96	4.30	98	8.0

[1] Nitrogen present in nutrient salt mixtures: In No. 3, ⅓ N as NH_4, and ⅔ N as NO_3; in No. 5, all N as NO_3.

The failure of the extra potassium applications to increase growth indicated that a potassium deficiency is not the cause of reduced growth in the pure sand cultures.

In pots receiving the all-nitrate salt mixture, all plants were markedly chlorotic during early growth, but toward the end of the experiment the color improved considerably and at that time the plants receiving extra iron were an almost normal green. The improved color at the later period when the heads were forming may be connected with an increase in the plants' requirement for potassium as compared with nitrogen, since an increase of this kind, if sufficient, would develop an acid reaction instead of an alkaline one in the absorption zone. The appearance of the plants and the yields indicated that the extra iron applications increased iron assimilation slightly but not to an optimum degree when this mixture of nutrient salts was applied.

COMPARATIVE YIELDS OF MILLET IN QUARTZ SAND AND IN SAND-SOIL OR SAND-PEAT MIXTURES, AS INFLUENCED BY THE WATER CONTENT AND BY FLUSHING

According to the ideas outlined in the introduction, unfavorable conditions for growth in pure sand cultures are developed in the zone of root absorption and do not necessarily obtain throughout the whole medium. It was thought that if the absorption zone could be flushed at intervals with the salt solution draining from the whole pot, growth should be as good in quartz sand as in sand-soil mixtures. The first experiment in which the pots were drained and flushed at intervals is described in the following paragraphs. This experiment was also designed to test an idea that had been expressed that better growth would be obtained in pots provided with drainage holes than in the standard closed crocks.

The pots used in this experiment were especially designed for drainage and held approximately 8,000 gm. of sand. The drainage holes of some pots were stopped with cotton and rubber cement, while the holes of other pots were left open. Half the pots were filled with quartz sand and half with a sand-Marshall soil mixture containing 1 percent of colloidal material. Most pots were maintained at a water content of 15 percent, but water was added to other pots until approximately 500 cc. percolated through. The 500 cc. of percolated solution was added to the pots at the next watering along with sufficient water to again provide a percolate of about 500 cc. For the 15 percent water content, 1,175 cc. of water was required, and for the drained pots, 2,763 cc. of water was required to produce the percolate of 500 cc. The sand and sand-soil mixtures in the drained pots thus held approximately 27 percent of water after drainage. The drained pots were filtered 11 times during the 27 days the experiment lasted. The standard mixture of nutrient salts, No. 3 of table 1, was applied to all pots. The quantity of salts was increased to eight-fifths of the normal quantity, however, since the pots in this experiment held approximately 8,000 gm. of sand instead of the usual 5,000 gm. Millet was grown from September 29 to October 26. The results of the experiment are shown in table 6.

TABLE 6.—*Effect of water content and drainage on yield of millet in quartz sand and a sand-soil mixture*

Material in pots	Kind of pots	Water content	Air-dry yield of individual pots			Average air-dry yield per pot
		Percent	*Grams*	*Grams*	*Grams*	*Grams*
Quartz sand only	No holes	15	6.47	4.48	5.47	5.47
Do	Holes	15	5.74	5.80	5.27	5.60
Do	do	27+	5.76	6.86	7.52	6.71
Sand plus Marshall soil	No holes	15	9.86	10.78	10.01	10.22
Do	Holes	15	10.78	9.90	10.41	10.36
Do	do	27+	9.00	7.56		8.28

It will be seen that the pure quartz sand and the sand-soil mixture, maintained at a water content of 15 percent, gave almost exactly the same yield in closed pots as in pots provided with holes in the bottom. Thus it is evident that the added aeration afforded by drainage holes does not improve growth conditions when the cultures are maintained at a favorable water content. The quartz sand culture flushed with excess water yielded about 20 percent more than the quartz sand of 15 percent water content; whereas the flushed sand-soil mixture yielded about 20 percent less than the same culture with 15 percent of water. The conclusion here is not certain, since the excess-water cultures differed from the standard cultures in three respects: (1) The excess-water cultures contained a less concentrated salt solution than the standard cultures, since the salts were dissolved in 2,763 cc. of water instead of in 1,175 cc.; (2) the pore space in the excess-water cultures remained filled with water after drainage, whereas the pore space in the standard cultures was little more than half filled by water; (3) the excess-water cultures were flushed 11 times during the experiment.

It is believed that in the case of the sand-soil mixtures the slightly

poorer growth in the flushed series than in the standard series was due to the second of the differences just mentioned. When the pore space is filled with water the decomposition of organic matter in the soil may be expected to produce unfavorable conditions. In the case of the pure quartz sand cultures, the slightly better growth in the flushed pots is believed to be due to the third difference. The flushing tended to remove the injurious conditions developed by the roots in the zone of absorption.

These conclusions seem little more than guesses when based on the data of this one experiment. They are, however, substantiated by other data. In connection with the results of the following experiment it is important to bear in mind that in this particular experiment any one or all three of the differences mentioned are responsible for only a slightly increased growth in the pure sand cultures.

It was thought that in the foregoing experiment the pots were not flushed frequently enough to maintain the solution in contact with the roots at approximately the same composition as the solution in the whole pot. Two more experiments were conducted in which the flushing was much more frequent.

In these experiments the regular 1-gallon crocks with drainage holes drilled in the bottom were employed. The all-ammonia mixture of nutrient salts, No. 1 of table 1, was used instead of the standard mixture, in order to provide a more severe test of the efficacy of flushing. With this mixture of salts, growth of millet in quartz sand cultures is especially poor, being only about one-fifth of that obtained in good sand-soil or sand-peat mixtures. Automatic flushing was provided by a siphon dripping from a 5-gallon bottle into a Soxhlet tube. The Soxhlet tube emptied 200 cc. of solution into the pot every hour or two. Such a large volume of water was required for flushing with this apparatus that distilled water could not be used without inordinately reducing the salt concentration in the pot; hence a salt solution was used that contained for every 1,400 cc. of water the quantity of salts applied to one pot. The solution was adjusted to pH 5.5 with sodium hydroxide. As a check on the effect of frequent flushing, some pots were made up with 1,400 cc. of water, which was the maximum amount a pot would hold after excess water had been added and allowed to drain away. After the plants had attained some size, these pots were flushed every 2 days with 200 to 500 cc. of the same solution as that applied to the frequently flushed pots. As a check on the efficacy of flushing, a series of pots was installed with a sand-peat mixture. The peat was a commercial material used for soil improvement and had been limed to a pH of 5.5. It was mixed with the sand in the proportion of 25 gm. of peat to approximately 5,000 gm. of sand.

Automatic flushing could not be started until the plants in the sand were about 1½ inches tall and those in the sand-peat mixture were somewhat taller. The effect of flushing the pots as soon as the plants were up was tried, but the solution burned the leaves badly. In the first experiment the plants were grown from October 24 to December 12 and in the second from January 24 to March 17. The greater growth in the second experiment was due to the more favorable light conditions obtaining in the second period. The results of the two experiments are shown in table 7.

TABLE 7.—*Effect of frequent flushing on yield of millet in quartz sand and in a sand-peat mixture*

Material in pots	Water content of pots	First experiment			Second experiment		
		Air-dry yield of individual pots		Average air-dry yield per pot	Air-dry yield of individual pots		Average air-dry yield per pot
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Quarts sand only	Normal, 15 percent	0.51	0.58	0.55	1.00	1.15	1.08
Do	Occasional flushing	.60	------	.60	1.37	1.60	1.49
Do	Frequent flushing	2.06	------	2.06	5.20	4.58	4.89
Sand plus peat	Normal, 15 percent	2.94	3.86	3.40	8.32	8.10	8.21
Do	Frequent flushing	1.66	1.29	1.48	6.45	6.92	6.69

It is apparent from the results shown in tables 6 and 7 that flushing the pots had a very different effect on pure sand cultures from that on sand cultures containing a small amount of soil or peat. Occasional flushing of the sand-soil mixture depressed the yield slightly, and frequent flushing had the same effect. In the pure sand cultures occasional flushing increased the yield only slightly, but frequent flushing increased the yield so markedly that it seems that this treatment may improve growth conditions in somewhat the same way as soil or peat admixtures. The failure of plants in frequently flushed sand to attain the growth made by plants in the sand-peat mixture is doubtless due in part to the fact that flushing could not be started until the plants were 10 or 11 days old. Possibly, also, frequent flushing did not so fully correct conditions as did the peat admixture.

It is felt that the experiments on flushing strongly support the idea that the beneficial effect of soil or peat admixtures on quartz sand cultures lies in correcting adverse conditions that develop in a zone contiguous to the roots.

COMPARATIVE YIELDS OF MILLET IN QUARTZ SAND AND IN A SAND-SOIL MIXTURE, AS INFLUENCED BY THE MECHANICAL COMPOSITION OF THE SAND

The data that have been discussed were obtained with many different lots of quartz sand, but they were all of approximately the same mechanical grade. Two-thirds of the particles were between 1.0 and 0.5 mm. in diameter. It seemed desirable to determine whether the effects of soil admixtures would be more or less pronounced with other grades of sand. An experiment was therefore begun in which coarser and finer grades of sand were compared with the standard grade. The mechanical analyses of the three kinds of sand (table 8) were made by E. F. Miles, of the Bureau of Plant Industry.

In this experiment the standard mixture of nutrient salts was used and the Spearfish soil was applied at a rate to supply 50 gm. of colloid per pot. Millet was grown from November 1 to December 13.

The results of the experiment were not very informative. The fine grade of sand, both with and without the soil admixture, was so compact that the roots penetrated it only slightly. Many of the roots formed later arched out of the sand without the tips penetrating. A mixture of 25 percent of the finer grade and 75 percent of the stand-

TABLE 8.—*Mechanical composition of three grades of quartz sand*

Diameter of particles (mm.)	Particles in sand of indicated grade		
	Coarse	Standard	Fine
	Percent	*Percent*	*Percent*
2+	27.1	0	0
2–1	68.6	16.7	0
1–0.5	3.7	64.8	.2
0.5–0.25	.5	17.4	1.5
0.25–0.1	.1	.9	84.6
0.1–0.05	0	0	13.1
0.05–0.005	0	0	.6

ard grade was likewise too compact for normal root growth. With the standard grade of sand the soil admixture produced the usual increase in growth. The average weight of plants in this pure sand was 1.61 gm. per pot, and in the sand-soil mixture the weight was 2.43 gm. With the coarser grade of sand the effects of the soil admixture were more pronounced. The pure sand yielded 0.51 gm. per pot and the sand-soil mixture 2.14 gm.

The preceding results indicate that the coarser the sand the more beneficial is the addition of soil. However, in the case of the coarse sand it is possible that part of the beneficial effect of the soil was due to improvement in the water-holding capacity of the medium. In the coarse sand without soil the plants wilted somewhat even when the water content was only slightly reduced.

COMPARATIVE YIELDS OF WHEAT IN QUARTZ SAND AND IN A SAND-SOIL MIXTURE, AS INFLUENCED BY THE MIXTURE OF NUTRIENT SALTS APPLIED

Most measurements of the increased yields produced by adding soil to sand cultures were obtained with millet, but apparently the results apply to most plants. Results similar to those shown by millet were observed with rice (*Oryza sativa* L.), white mustard (*Brassica alba* (L.) Boiss.), cotton (*Gossypium* sp.), and dwarf sunflowers (*Helianthus* sp.). Marquis wheat, on the other hand, yielded almost as much in pure quartz sand as in sand-soil mixtures in several experiments, some of which have been published *(5, 6)*.

It was thought probable that this exceptional behavior of wheat was characteristic only of the particular mixture of nutrient salts applied. An experiment was therefore conducted with a series of nutrient salt mixtures in which the source of nitrogen ranged from all nitrogen as ammonia to all nitrogen as nitrate. The composition of these salt mixtures is shown in table 1. Each of the mixtures contained practically the same quantities of nitrogen, phosphorus, potassium, magnesium, sodium, and minor nutrients, but some mixtures contained different quantities of calcium, sulfate, or chlorine. The soil added to one series of pots, at the customary rate of 50 gm. of colloid per 5,000 gm. of sand, was a sample of the Nacogdoches fine sandy loam having a pH value of 6.3. Marquis wheat was grown from December 11 to January 22. The results of the experiment are given in table 9.

Evidently the growth of wheat in sand cultures may be markedly improved by a soil admixture when the nutrient salts contain an undue

Table 9.—*Effect of different nutrient salt mixtures on yield of wheat in quartz sand and in a sand-soil mixture*

Nutrient salt mixture		Material in pots	Air-dry yield of individual pots				Average air-dry yield per pot	Yield in sand-soil culture as percentage of yield in sand	Hydrogen-ion concentration of medium at—	
No.	Form of nitrogen present								Start of experiment	End of experiment
			Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Percent*	*pH*	*pH*
1	All as NH_4	Sand only	1.05	0.80	0.80	0.83	0.87	100	6.0	4.4
2	½ as NH_4	Sand only	2.48	2.32	2.33	2.01	2.29	100	6.0	4.7
3	⅓ as NH_4	Sand only	2.37	2.27	2.37	2.11	2.28	100	6.0	5.2
4	⅙ as NH_4	Sand only	2.75	2.60	2.43	2.76	2.64	100	6.0	6.8
5	All as NO_3	Sand only	1.72	1.95	1.82	2.15	1.91	100	6.7	8.6
1	All as NH_4	Sand plus soil	2.20	2.13	1.96	1.92	2.05	236	6.0	4.6
2	½ as NH_4	Sand plus soil	2.82	2.40	2.98	2.64	2.71	118	6.0	5.0
3	⅓ as NH_4	Sand plus soil	2.21	2.42	2.53	2.58	2.44	107	6.0	5.8
4	⅙ as NH_4	Sand plus soil	2.28	2.44	2.60	2.72	2.51	95	6.0	6.5
5	All as NO_3	Sand plus soil	2.27	2.68	2.77	2.01	2.43	127	6.0	7.6

proportion of either essential cations or anions, as in the case of the all-ammonium and all-nitrate mixtures. But when the standard salt mixture No. 3 was used, the increase produced by soil was only 7 percent in this experiment, and in seven other comparisons involving four different soils the average increase was 9 percent. On the whole, wheat seems less sensitive than millet to conditions in quartz sand, for when the No. 3 salt mixture is used a soil admixture usually increases the growth of millet about 50 percent. And the increases produced in wheat by the application of soil with the other salt mixtures are smaller than those usually produced in millet under similar conditions.

Although wheat seems more tolerant than millet or rice of conditions obtaining in quartz sand cultures, it seems to alter the hydrogen-ion concentration of the medium to about the same extent as millet or rice, as shown by table 10.

TABLE 10.—*Hydrogen-ion concentration of quartz sand after growth of millet, wheat, and rice with different nutrient salts*

Nutrient salt mixture		Hydrogen-ion concentraton of quartz sand after growth of—		
No.	Form of nitrogen present	Millet	Wheat	Rice
		pH	*pH*	*pH*
1	All as NH_4	3.8	4.4	----
2	½ as NH_4	4.3	4.7	4.4
3	⅓ as NH_4	5.5	5.2	5.5
4	⅙ as NH_4	5.8	6.8	7.3
5	All as NO_3	7.1	8.6	----

This comparison is not conclusive since the data are the results of single experiments and the hydrogen-ion concentrations developed by millet have been found to vary considerably in experiments conducted at different times. Presumably all conditions that affect the ash composition of the crops would affect the hydrogen-ion concentrations developed. It seems probable, however, from the data at hand, that modifications in the hydrogen-ion concentrations produced by the growth of wheat are not widely different from those produced by millet and rice.

RECAPITULATION OF EVIDENCE CONCERNING THE BENEFICIAL EFFECT OF SOIL ADMIXTURES IN QUARTZ SAND CULTURES

The experimental results reported in this and a previous publication (*3*) strongly support the explanation that has been given for the beneficial effect of adding soil to a quartz-sand culture. The general features of the explanation are that in pure quartz sand an unfavorable hydrogen-ion concentration is developed, owing to a nonequivalent absorption of cations and anions; that the soil admixture improves growth by acting as a buffer to the hydrogen-ion concentration developed; and that the soil also supplies available iron. A recapitulation of evidence bearing on these assumptions follows.

That the roots develop a hydrogen-ion concentration owing to the nonequivalent absorption of nutrient cations and anions was shown by experiments conducted with millet (*3*) and wheat in quartz sand. In these experiments mixtures of nutrient salts containing different proportions of ammonium and nitrate ions were compared. When nitrogen was supplied exclusively as ammonium ions, the quartz sand became plainly too acid for the best growth; and when nitrogen was supplied exclusively as nitrate, the sand became plainly too alkaline, since the plants became chlorotic, owing to an insufficient absorption of iron. When one-third of the nitrogen was supplied in the form of ammonium and two-thirds as nitrate, as in the standard salt mixture, the sand was somewhat more acid at the end of growth than at the beginning. But the acidity developed was not sufficient to curtail growth markedly, if one judged by the hydrogen-ion concentration of all the sand in a pot before and after an experiment. In fact, some sand-soil mixtures were more acid than the pure quartz sand cultures at both times of examination.

However, examination at intervals during growth of sand adhering to the roots showed that, when the standard salt mixture is used, sand close to the roots may be highly acid during early growth and nearly neutral to alkaline during later growth. It appeared, therefore, that hydrogen-ion determinations of all the sand in a pot at the start and end of an experiment showed only the net acidity or alkalinity developed, and not the conditions affecting the roots at any time. Even when the hydrogen-ion concentration of the whole pot is near the optimum, the hydrogen-ion concentration very near the roots may be unfavorable a considerable part of the time.

The difference between conditions obtaining near the roots and throughout the pot is indicated also by the appearance of the plants. Usually the poorer growth of millet in quartz sand than in sand-soil mixtures is apparent when the plants are very small, only 1 to 2 inches tall. At this stage of growth the sand in the pot as a whole could have been altered little by the plants' absorption of ions. In a zone close to the roots, however, the reaction developed could be as unfavorable as that shown by the whole pot at the end of growth when nitrogen is supplied exclusively as ammonium or as nitrate.

Further evdence that in sand cultures an unfavorable condition may develop near the roots is provided by the flushing experiments. When the pots were flushed every 2 to 3 hours, growth was markedly improved in the sand cultures but slightly depressed in the sand-soil and sand-peat mixtures. When the sand cultures were flushed every

other day, there was only slight improvement in growth. These facts are in accord with the idea that the unfavorable conditions in sand cultures are strongly localized and develop quickly.

That the soil admixture improves growth by acting as a buffer to the hydrogen-ion concentrations developed is shown by several experiments, most of which are reported in a previous publication (*3*). When the standard salt mixture developing moderate acidity was used, growth in quartz sand was improved by such diverse materials as a neutralized sodium silicate, a ferric oxide gel, activated charcoals, samples of peat having pH values above 5.0, and calcium carbonate plus ferric tartrate. All of these materials had greater or less buffer capacities, especially against acid.

That the capacity of the soil for supplying iron is also concerned in the beneficial effect of soil additions, especially when an alkaline reaction is developed, is indicated by two facts. (1) When an all-nitrate salt mixture was applied to quartz sand, the plants became chlorotic, owing to an iron deficiency. This condition was partly corrected by adding extra iron to the sand. In the soil-sand culture the plants were green and were not improved by additional iron. (2) When a small amount of calcium carbonate was added to quartz sand fertilized with the standard mixture, growth was improved by only 15 percent; but calcium carbonate and extra iron together increased growth by 42 percent.

DISCUSSION

The results obtained in this study emphasize some of the important differences in soil, water, and sand cultures. In a soil culture the solution at the start may be quite different from the salt solution originally supplied, owing to reactions with the colloidal material. This applies particularly to concentrations of hydrogen and phosphate ions. And, since the salt solution is not renewed, it should change with the growth of the plants, except as it is stabilized by the soil colloids. The solution in contact with the roots should be somewhat different from that in the medium as a whole, owing to absorption by the roots, but creation of differences in the root zones is opposed by the colloidal material.

In a water culture, the solution in the container should at the start be the same as that originally supplied, and it should alter little with growth of the plants if the solution is frequently renewed. Also, the solution in contact with the roots should be practically the same as all the solution in the container, particularly if the solution is agitated by aeration. However, there is reason for believing that the solution in the absorption zone of roots may differ from that in the body of the container in the case of water cultures in which precipitates form and adhere to the roots.

Some conditions in a quartz sand culture are midway between those obtaining in water and soil cultures and some are more extreme. In a pure quartz sand culture the solution at the start should, as in a water culture, be the same as that originally supplied. Since the solution is not renewed and is not buffered by a reactive material, it should alter with the growth of the plants more than the solution in a soil culture. Also, the solution in immediate contact with the roots should differ from that in the whole container more markedly than in the case of soil or water cultures.

This difference between the solution in the whole container and in the absorption zone varies with the rate of diffusion from and into the absorption zone. It should also vary with the kind of plant and the composition of the nutrient solution. If a plant absorbed equivalent amounts of the nutrient cations and anions, the hydrogen-ion concentration of the absorption zone would remain neutral or the same as that in the container as a whole. The most pronounced changes in the reaction of the absorption zone are brought about by varying the proportions of ammonium and nitrate ions, since this involves a change in one of the major nutrients absorbed from cation to anion. Other differences in the composition of the nutrient solution should have comparatively little effect on the reaction developed by absorption, since no other major nutrient can be supplied as either cation or anion.

It might be supposed that in sand cultures any hydrogen-ion concentration between pH 4 and 7 could be attained by properly apportioning the nitrogen between ammonium and nitrate ions. This is approximately true for the reaction of the whole medium at the end of a growth period, provided the nitrogen supply is largely utilized. It does not seem to apply, however, to sand close to the roots. Near millet and wheat roots the reaction of the sand may vary between early and later growth from markedly acid to nearly neutral or alkaline, when certain proportions of ammonium and nitrate ions are supplied; when other proportions of ammonium and nitrate are supplied the reaction may remain strongly acid during the whole period. The early acidity developed is doubtless due to the fact that most plants, especially young ones, absorb ammonium ions more rapidly than nitrate. The shift from acidity to alkalinity that sometimes occurs is probably due to a depletion of the ammonium ions.

Even the reaction of the whole culture at the end of a growth period cannot be accurately controlled by varying the proportions of ammonium to nitrate unless the total application of nitrogen is adjusted to growth conditions. Hydrogen-ion determinations have been made on all the sand in a pot after growth of the plants in 14 experiments conducted at different times of the year. In all experiments the same quantity of the 1/3-ammonium, 2/3-nitrate salt mixture was applied. The hydrogen-ion concentrations ranged from pH 4.5 to 6.2 in different experiments, and were closely correlated with the dry weights of the crop. The more acid reactions were obtained in experiments where the growth was less.

It is not certain that a root zone maintained in a wholly neutral condition would be especially favorable for growth. Under such conditions the plants might suffer from an iron deficiency. When water cultures are kept nearly neutral, special procedures have to be followed to keep the plants supplied with available iron. One procedure is to grow the plants part of the time in a phosphate-free solution, where the iron is more available. Another method is to supply the iron in organic form as ferric tartrate or ferric citrate. The solution, however, should be renewed frequently, since the iron does not remain available long even when supplied in these forms. The ferric tartrate dissolves under the influence of sunlight into a ferrous form that reacts with potassium ferricyanide, but as the solution is aerated the iron is precipitated as ferric hydroxide. A third method that has been followed by Von der Crone (*1*) and Zinzade (*12*) is to supply a large amount of iron as ferric phosphate.

It is probably not sufficiently appreciated that the reaction developed where the root is absorbing may be quite different from that of the medium as a whole. It was found by one of the authors years ago that pineapples and rice became chlorotic owing to lack of available iron in calcareous soils but did not become chlorotic in soils rendered alkaline with sodium bicarbonate (*4*). This discrepancy was not explained at the time. Since the nitrogen in these experiments was supplied as ammonium sulfate, it is probable that the plants developed sufficient acidity in the absorption zone to neutralize the sodium bicarbonate in that zone and render iron available, but not sufficient acidity to neutralize the calcium carbonate in contact with the roots. Possibly this theory may explain some of the exceptions found in the distribution of acid-loving plants.

SUMMARY

In a previous publication (*3*) it was shown that millet does not grow so well in pure quartz sand as in quartz sand to which a little soil has been added. How the soil admixture improves growth was not shown with certainty. An answer to this question is provided by data reported in the present paper.

The beneficial effect of a soil admixture with quartz sand appears to be due to the buffer capacity of the soil and to its capacity for supplying iron.

In pure quartz sand unfavorable hydrogen-ion concentrations may develop, owing to the nonequivalent absorption of cations and anions. If the nutrient salts contain all the nitrogen in the form of ammonium, the sand becomes markedly acid; and if the nitrogen is applied exclusively as nitrate, the sand becomes alkaline or so nearly neutral that absorption of iron is inhibited. If nitrogen is supplied partly as ammonium and partly as a nitrate, the reaction is markedly acid at first, owing to ammonium ions being absorbed more rapidly than nitrate ions; later, the reaction developed may be nearly neutral or alkaline if the ammonium ions are sufficiently depleted. This occurred in experiments in which a salt mixture was used that contained one-third of the nitrogen as ammonium and two-thirds as nitrate. In this case hydrogen-ion determinations made on all the sand in a pot at the end of growth showed only the net acidity developed and did not show conditions existing near the root at different times during growth. Sand adhering to the roots may differ widely in reaction from all the sand in a pot. In sand cultures containing soil admixtures, the development of unfavorable reactions in the zone of root absorption is opposed by the soil colloids. The soil colloids may also improve growth by supplying iron in case a nearly neutral or alkaline reaction is developed.

Differences in soil, sand, and water cultures as mediums for growth are pointed out, and the importance of considering the hydrogen-ion concentration of the zone contiguous to the root, rather than that of the whole medium, is emphasized.

LITERATURE CITED

(1) Crone, G. von der.
1904. Ergebnisse von untersuchungen über die wirkung der phosphorsäure auf die höhere pflanze und eine neue nährlösung. 46 pp. Bonn. (Inaug. Diss.)

(2) GILE, P. L.
1933. THE EFFECT OF DIFFERENT COLLOIDAL SOIL MATERIALS ON THE EFFICIENCY OF SUPERPHOSPHATE. U. S. Dept. Agr. Tech. Bul. 371, 59 pp., illus.
(3) ———
1939. GROWTH OF MILLET IN QUARTZ SAND AND IN SAND-SOIL MIXTURES. Jour. Agr. Res. 59: 619–633.
(4) ——— and CARRERO, J. O.
1920. CAUSE OF LIME-INDUCED CHLOROSIS AND AVAILABILITY OF IRON IN THE SOIL. Jour. Agr. Res. 20: 33–62, illus.
(5) ——— and LAKIN, H. W.
1941. EFFECT OF DIFFERENT SOIL COLLOIDS ON THE TOXICITY OF SODIUM SELENITE TO MILLET. Jour. Agr. Res. 63: 559–581.
(6) ——— LAKIN, H. W., and BYERS, H. G.
1938. EFFECT OF DIFFERENT SOIL COLLOIDS AND WHOLE SOILS ON THE TOXICITY OF SODIUM SELENATE TO MILLET. Jour. Agr. Res. 57: 1–20, illus.
(7) NIGHTINGALE, G. T.
1934. AMMONIUM AND NITRATE NUTRITION OF DORMANT DELICIOUS APPLE TREES AT 48° F. Bot. Gaz. 95: 437–452.
(8) SOLBERG, P.
1935. UNTERSUCHUNGEN ÜBER DIE WURZELAUSSCHEIDUNGEN VERSCHIEDENER PFLANZEN BEI IHRER KULTURE OHNE UND MIT ZUSATZ VON NÄHRSALZEN. Landw. Jahrb. 80: 891–917, illus.
(9) STAHL, A. L., and SHIVE, J. W.
1933. FURTHER STUDIES ON NITROGEN ABSORPTION FROM CULTURE SOLUTIONS: II. BUCKWHEAT. Soil Sci. 35: 469–483, illus.
(10) TRELEASE, S. F., and TRELEASE, H. M.
1935. CHANGES IN HYDROGEN-ION CONCENTRATION OF CULTURE SOLUTIONS CONTAINING NITRATE AND AMMONIUM NITROGEN. Amer. Jour. Bot. 22: 520–542, illus.
(11) WADLEIGH, C. H., and SHIVE, J. W.
1939. BASE CONTENT OF CORN PLANTS AS INFLUENCED BY PH OF SUBSTRATE AND FORM OF NITROGEN SUPPLY. Soil Sci. 47: 273–283.
(12) ZINZADE, S. R.
1927. NEUE NORMALE NÄHRLÖSUNGEN MIT STABILER REAKTION (PH) WÄHREND DER VEGETATIONSPERIODE. Landw. Vers. Sta. 105: [267]–332, illus.

504160—43——2

STUDIES OF SOME FACTORS AFFECTING FRUIT SETTING IN SOLANUM TUBEROSUM IN THE FIELD IN LOUISIANA [1]

By M. T. HENDERSON, formerly *agent*, and E. L. LECLERG, *pathologist, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, Agricultural Research Administration, United States Department of Agriculture*

INTRODUCTION

Nonfruitfulness of the potato (*Solanum tuberosum* L.) greatly complicates improvement through breeding. Location of the breeding operations in areas found by experience to be favorable for fruit setting will partly eliminate the handicap. However, the limited number of these areas places a serious restriction on the amount of breeding work that can be done.

Nonfruitfulness is due mainly to pollen sterility in many varieties or to premature abscission of flowers before fertilization can occur. These handicaps greatly complicate the problem of improvement through breeding by increasing the amount of labor necessary to obtain seedling populations, by limiting the size of many progenies, and by making certain crosses impossible so that many combinations cannot be tested.

In most localities where potato breeding is under way, more attention has been given to nonfruitfulness due to pollen sterility than to that resulting from premature abscission of flowers. However, under controlled conditions in Louisiana, the latter constitutes as great a handicap as lack of viable pollen, or even greater. This is true probably because environmental conditions are frequently unfavorable for fruit setting in bags under field conditions in Louisiana.

Because pollen sterility and premature flower shedding are to a great extent genetically controlled, data showing the degree of both conditions in all varieties used as breeding material should have practical value. Therefore, these investigations were made to study (1) the extent of pollen sterility in named and seedling varieties, (2) the effect of bagging of flowers on fruit set, (3) the effect of stage of development and number of pollinations on fruit set, and (4) the effect of some natural environmental conditions on fruit set.

EXPERIMENTAL DATA

EXTENT OF POLLEN STERILITY IN NAMED AND SEEDLING VARIETIES

Stuart (*8*)[2] made the following statement with reference to pollen sterility in potatoes:

* * * In plant breeding studies extending over a period of sixteen years it has been the writer's privilege to examine the stamens of a great many varieties, and in but few instances has an abundance of viable pollen been found. The data show a very much larger proportion of foreign varieties producing viable pollen than of American varieties. Of the many varieties studied * * * only

[1] Received for publication May 25, 1942. Cooperative investigations with the Department of Horticulture, Louisiana Agricultural Experiment Station.

[2] Italic numbers in parentheses refer to Literature Cited, p. 75.

four were noted which could be regarded as dependable sources from which to obtain viable pollen.

Krantz and Hutchins (*4*) credited the prevalence of nonfruitfulness in the potato, due to flower abscission and pollen sterility, with being primarily responsible for the paucity of potato-breeding work. Stevenson and Clark (*7*) stated:

> Sterility, or lack of fruitfulness, which is very generally present in potato varieties, is the source of the greatest difficulty in sexual breeding, and in spite of much study of the condition it remains the greatest handicap of the potato breeder.

In order to obtain an estimate of the amount of viable pollen present in some varieties being used in potato breeding, percentages of pollen stainable in acetocarmine were calculated during the flowering seasons of 1940 and 1941. Percentages, based on counts of 100 grains from each of 3 flowers, and the relative amount of pollen per flower were determined for each variety.

Pollen grains of potato that absorb the acetocarmine stain have a nonstaining exine, are spherical in outline, and usually have four equidistant germ pores, or small openings, through which the pollen tubes emerge. The cytoplasm stains a uniform, deep red and does not always have the same shape as the exine; it may vary from spherical to almost square with cornerlike projections immediately beneath the germ pores. The cytoplasm of normal grains is very finely granular. These stainable grains may vary considerably in size within a clone. Pollen classed as abortive may vary from shrunken, wrinkled, hyaline exines without any trace of cytoplasm to grains normal in shape and size but having numerous lightly staining or nonstaining alveolate or vacuolelike structures embedded in the differentially staining cytoplasm.

The stainability and relative abundance of pollen of 36 varieties and seedling varieties are presented in table 1. From these data it appears that the higher percentages of pollen stainable are usually associated with relatively large amounts of pollen grains. From experience, it appears that only varieties having a medium or abundant quantity of pollen and with at least 30 percent of it stainable can be used successfully as pollen parents. With a knowledge of the percentage of pollen stainable, a breeding program can be planned with a minimum of wasted effort. Approximately two-thirds of the varieties listed in table 1, representing some of the important breeding material in the United States, cannot satisfactorily be used as male parents. Obviously, hybridization is seriously limited by the scarcity of genetically valuable parents that produce good pollen.

EFFECT OF BAGGING OF FLOWERS ON FRUIT SET

A few reports on the influence of flower isolation and type of isolator on fruit set of the potato are available in the literature. Salaman (*6*) and East (*2*) considered the covering of potato flowers with bags as unnecessary and likely to cause injury to the delicate style. The former worker stated that "when bagged, the flower invariably drops." East (*2*) implied that shutting out light and preventing air circulation by bagging reduced the percentage of fruit set.

TABLE 1.—*Stainability and relative abundance of pollen in varieties and seedling varieties of potatoes tested at Baton Rouge, La., 1940 and 1941*

Variety or seedling	Pollen stainable		Relative amount of pollen
	1940	1941	
	Percent	*Percent*	
Ackersegen	16.0		Very scarce.
Albion	25.5	8.3	Medium.
Arnica [1]	45.3		Do.
Chippewa	11.0	7.5	Scarce.
Earlaine [1]	62.5	42.7	Abundant.
Early Rose	12.5	1.0	Very scarce.
Green Mountain	16.1		Medium.
Hindenburg [1]	51.6	44.0	Do.
Houma	6.7	5.0	Very scarce.
Irish Cobbler		3.7	Scarce.
Katahdin [1]	72.0	56.7	Abundant.
Pennigan	16.0		Very scarce.
Pontiac		45.0	Scarce.
Richter Jubel	34.0	20.0	Medium.
Sebago	16.6	3.0	Scarce.
Sebec [1]		70.7	Abundant.
Sequoia	38.1	[2]	Scarce.
Shamrock [1]	45.5	45.5	Medium to abundant.
Triumf [1]		38.7	Medium.
Triumph	8.7	6.7	Very scarce.
S45941 [1]	55.3		Medium.
S46000	9.5		Very scarce.
S46442 [1]	59.1	31.0	Medium.
S46244		11.3	Abundant.
S46926 [1]	46.0		Medium to abundant.
S47140	73.0		Very scarce.
S47142		5.0	Do.
S47148	25.3		Scarce to medium.
S47182 [1]		31.0	Medium.
S47194		1.3	Medium to abundant.
S47402	19.5		Scarce to medium.
B–127	26.4	23.0	Medium.
X570–84 [1]	32.3	40.0	Abundant.
Y528–34		3.0	Scarce.
X528–170 [1]		46.0	Abundant.
X528–175		4.5	Medium.

[1] Variety that can be feasibly used as pollen parent.
[2] No pollen.

However, Stuart (*8*) stated:

While it is true that the pistil of the flower is easily broken off, and that few insects visit the flowers, it is not necessarily true that the inclosure of the emasculated flowers in paper bags causes any more of them to drop off than if left uncovered, provided the operator follows the suggestion given relative to including as much foliage with the flowers as is possible.

And Lunden (*5*) stated:[3]

For the control of pollination sometimes parchment bags and sometimes manila bags were used. Where it has been difficult to get a good development of the tops in small closed bags, large bags were used, enclosing part of the upper leaves in the bag. In this way the danger of foreign pollination is practically excluded, while giving a chance for some ventilation. This method has given good results.

Uspenskii (*9*) listed three methods of isolation in general use in Russia, namely, enclosing in cloth or parchment bags and covering the pollinated stigma by a short piece of straw tube. He reported that isolation on the whole tends to lower the percentage of fruit set as compared with that of nonisolated controls. Of the three kinds of isolation, parchment bags gave the best fruit set, and the straw isolators gave the lowest percentage of seed. However, when pollinations were made during rainy weather, the straw isolators ranked

[3] From translation by Margareta Ahlquist; made under the supervision of F. A. Krantz, Division of Horticulture, Minnesota Agricultural Experiment Station. [Processed.] See p. 25.

highest in percentage of fruit set and parchment bags ranked higher than the unbagged controls. He explained this difference by the fact that isolators protect the stigma from rain.

Stevenson and Clark (7) stated that in the potato-breeding work of the United States Department of Agriculture at Beltsville, Md., the emasculated and pollinated inflorescence is enclosed in a 1-pound paper bag.

In the present work the fruit set under two kinds of bags, kraft-paper bags and cheesecloth bags stretched over wire frames, was tested in comparison with that of nonbagged controls in 1940. In 1941 only kraft-paper bags were used.

Plants that had several buds per cyme in the proper stage for making pollinations were selected. Only buds that would have opened normally within the next 2 days were chosen for the test, and all open flowers and immature buds on the selected cymes were removed. Usually three to six buds per flower cluster were left for pollination. On these buds about three-fourths of each calyx and corolla was removed with a pair of sharp-pointed tweezers, exposing the stamens and pistil. Emasculation was accomplished by placing the point of the tweezers against the inner surface of the firm fleshy anthers and pushing outward. In this manner the anthers were broken off just below their base with the least amount of injury to the slender, easily broken pistil. Furthermore, this method eliminated the danger of leaving portions of anthers, which occurs often when the anthers are pulled away. Immediately after emasculation the flowers were pollinated by holding them at the base and dipping the stigma into a mass of fresh pollen collected in a small shallow container.

In each case a small amount of foliage was enclosed in the bag with the cyme. This practice has been found to increase the percentage of fruit set, probably because the leaves maintain higher humidity and lower temperatures in the bags than would be the case without them. A small cardboard tag on which all essential information was recorded was attached to the stem by a string. After pollination each cyme was enclosed in one of the two types of bags used in the test. Care was taken to prevent injury to the flowers.

The results of controlled pollinations obtained under field conditions in the course of controlled pollination work in 1940 indicate that, at least in this experiment, fruit set with both methods of bagging was lower than in the nonbagged controls (table 2). Kraft-paper bags yielded slightly better results than cheesecloth bags. During 1940 the environmental conditions were unfavorable for fruit set, as the temperature was relatively high and soil moisture and atmospheric humidity were low. Very few naturally pollinated fruits were formed on Katahdin plants in the same field.

The results of controlled pollinations for 1941 substantiate those obtained in 1940, in that bagging of flowers caused a substantial reduction in percentage of fruit set as compared with that in nonbagged controls (table 2). In 1941 the weather conditions from May 2 to 4 were considered favorable for fruit set, so that the difference obtained on May 2 probably represents more nearly the condition one would normally expect. The maximum temperature had become relatively high for fruit setting by May 7.

TABLE 2.—*Effect of bagging on fruit set at Baton Rouge, La., in 1940 and 1941*

Isolation treatment	Date of treatment	Variety	Nature of pollination	Flowers pollinated	Flowers setting fruits	
				Number	*Number*	*Percent*
CONTROLLED POLLINATIONS UNDER FIELD CONDITIONS						
Kraft-paper bags	May 1, 1940	Katahdin	Selfing	130	3	2.3
Cheesecloth bags	do	do	do	31	0	.0
Do	do	Katahdin × (X570-84)	Cross	32	0	.0
None	do	Katahdin	Selfing	110	18	16.3
Kraft-paper bags	May 2, 1941	do	do	81	16	19.8
None	do	do	do	75	21	28.0
Kraft-paper bags	May 7, 1941	do	do	49	0	.0
None	do	do	do	37	5	13.5
REGULAR POLLINATIONS IN FEDERAL BREEDING PLOT						
Kraft-paper bags	Spring, 1940	Many	Crosses	466	79	16.9
None	do	do	do	292	58	19.8

The results of regular pollinations made in the spring of 1940 in the Federal breeding plots are also presented in table 2. These data, which represent the result of crosses of many different varieties and seedlings, tend to substantiate the previous findings that a slightly higher percentage of nonbagged flowers developed into fruit than did bagged ones.

The results of all trials uniformly show that isolation with cheesecloth or kraft-paper bags was detrimental to fruit setting under Louisiana conditions during 1940 and 1941. The cheesecloth bags were unsatisfactory in several respects. Wire frames had to be used in conjunction with them; more time was spent in applying them than paper bags; injury to essential flower parts was greater than when paper bags were used; and the fruit set was lower than when kraft-paper bags were used. On the other hand, kraft-paper bags, if used when weather conditions were generally favorable to fruit setting, gave a satisfactory percentage of successful pollination, allowing the breeder to obtain adequate seed supplies with assurance of purity.

It would appear from the literature and the results herein presented that any method of isolation of potato flowers will reduce fruit set because of their sensitivity to even slightly unfavorable environmental conditions. Bagging affects the temperature and humidity immediately surrounding pollinated flowers, probably causing more unfavorable conditions than prevail under normal field conditions.

EFFECT OF STAGE OF FLOWER DEVELOPMENT AND OF NUMBER OF POLLINATIONS ON FRUIT SET

There is no generally accepted policy among potato breeders concerning the number of pollinations necessary to give maximum fruit set or the optimum stage of flower development for such pollinations.

Stuart (*8*) recommended that flowers for controlled pollinations be emasculated 24 hours before the buds normally open. Pollen was then applied 1 or 2 days after emasculation. Uspenskii (*9*) stated that in controlled pollinations in Russia, 2 to 3 days elapse between the time of emasculation and pollination. Apparently, only one pollination is practiced. Flowers were enclosed in isolators from the

time of emasculation. Uspenskii presented evidence indicating that pollination repeated three times at different hours of the day gave a low percentage of fruit set and stated that this may be due to unnecessary irritation or injury of the stigma in the pollination process. From his results it appeared that repeated pollination decreased the percentage of fruit set when made during the afternoon and increased fruit set when made during the morning.

During 1940 data were collected to determine the effect of one and two pollinations, respectively, on fruit set. In both seasons the Katahdin variety was self-pollinated. Buds were selected that would normally have opened within 1 or 2 days. All flowers included in the test were emasculated, and the first pollination was made at that time. Those flowers given two pollinations were repollinated approximately 24 hours after emasculation and the first application of pollen. None of the cymes was bagged. In 1941 the work was broadened to include the influence on fruit setting of the stage at which flowers were pollinated. In addition to the two treatments given in 1940, some flowers were not pollinated at the time of emasculation but were given a single application of pollen about 24 hours after emasculation, or at about the time they would ordinarily be repollinated. The test was conducted over a 2-day period.

The results given in table 3 indicate that pollination at the time of emasculation was relatively ineffective in inducing fruit set. Also, the results suggest that, with two pollination treatments, beginning on the date of emasculation, the second application of pollen is far more effective than the first. Since there was apparently little or no difference in fruit setting from a single pollination made on the day following emasculation and from two pollinations, one on the day of and another on the day after emasculation, the former method seems preferable and more efficient from the standpoint of time and labor.

The two most probable reasons for poor fruit set from pollination at the time of emasculation seemed to be either that the stigma was not receptive and pollen would not germinate and penetrate the style at the time, or the pollen germinated and the tubes penetrated the style but the ovules were still immature and incapable of being fertilized. The first explanation appears logical when it is recalled that emasculation was performed while the flower was in the bud stage, about 1 or 2 days before anthesis. However, a high percentage of pollen grains placed on the stigmas of emasculated buds germinated quickly and penetrated the style in a normal manner, apparently eliminating the first hypothesis. It appears probable that the ovules are too immature to permit fertilization in the bud stage, and most of the pollen tubes from pollen applied to the stigma at this time deteriorate without effecting fertilization.

EFFECT OF SOME NATURAL ENVIRONMENTAL CONDITIONS ON FRUIT SET

References have been frequently made to the striking influence of environment on fruit setting under controlled pollination in the potato. Young (*10*) stated that degenerative changes in the ovule and embryo sac result from unfavorable environmental conditions which cause blasting of the flowers. Krantz and Hutchins (*4*) and Krantz et al. (*3*) obtained conclusive evidence that flower abscission is influenced to a considerable degree by environment.

TABLE 3.—*Effect of one and two pollinations on fruit set of selfed Katahdin potato under field conditions*

Date of first pollination	Pollinated—					
	At emasculation		24 hours after emasculation		At emasculation and 24 hours later	
	Flowers pollinated	Flowers setting fruit	Flowers pollinated	Flowers setting fruit	Flowers pollinated	Flowers setting fruit
1940	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
April 15-20	62	1.6			59	42.2
1941						
April 30	78	.0	87	17.2	88	1.1
May 1	88	10.3	78	25.6	75	28.0
Total or average	166	5.1	165	21.4	163	14.5

Semsroth, according to Clark (*1*), found that the best climatic conditions for the setting of fruit were a low daily mean temperature (about 65° F.) with a low maximum temperature (about 72°). A poor set resulted from a high mean daily temperature of 70° or higher, from a very low minimum and a high maximum, and from a relatively low air humidity and heavy showers on the days of emasculation and pollination.

Stevenson and Clark (*7*) stated:

> Because of the effect of environment on the fruitfulness (seed production) of potato plants, it is difficult, if not impossible, for many of the State experiment stations interested in some aspect of potato-breeding work to produce true seed. * * * Certain Northern States and other States with mountainous regions where potatoes can be grown at high elevations are especially favored * * * * * * * * * * * * * * * But seed setting is also influenced by environmental factors to a marked degree. Some varieties will set seed under a wide range of conditions, while others have never been known to set seed even under favorable conditions. * * * * * * * * * * * * * * * Conditions are favorable nearly every season at Presque Isle. A few other places in the United States have been found favorable for seed production * * *. At Estes Park, Colo., which has an elevation of 7,500 feet, seed sets in most years quite readily.

In 1940 and 1941, during the course of the regular breeding work at Baton Rouge, La., records were kept of the date of pollination, number of flowers pollinated, and the number of fruit set. Compilation of these data according to date of pollination brought out some interesting relationships between environment and fruit setting in the potato. The data for the 2 years are presented in table 4.

From the data in table 4, it is apparent that in 1940 the percentage of flowers that set fruits was progressively less each day after pollination work was started on May 2. A record of weather conditions at Baton Rouge for this period indicates that the mean temperature varied markedly during the pollination period, May 2 to May 15. The mean temperature during the 10 days preceding May 2 was relatively low, and the minimum temperature for May, 51° F., was recorded on May 2. Beginning with May 4, the mean temperature rose gradually until the highest temperature for the month, 90°, was recorded on May 16. The weather report for the period shows 2.5

inches of rainfall during the 10 days previous to May 2, which was the first and most successful date of pollination. This provided high soil moisture and atmospheric humidity for development of the flower buds during the first 2 or 3 days of pollination. On each date after May 2 soil moisture and atmospheric humidity became noticeably lower. Rising daily temperatures and declining soil moisture characterized the period from May 4 to May 15 and probably were the principal causes of the low fruit set after May 4. Very few naturally pollinated fruits developed on normally highly fertile varieties during that period; this also indicates the influence of unfavorable weather conditions. Thus, it seems that a combination of declining soil moisture and humidity and rising daily temperatures was probably the most influential factor in the daily decrease in percentage of flowers that set fruits from May 2 to May 8.

TABLE 4.—*Fruit set on different dates of pollination during the regular pollination work, Baton Rouge, La., in 1940 and 1941*

Date of pollination	Flowers pollinated	Flowers setting fruit	Date of pollination	Flowers pollinated	Flowers setting fruit
1940	*Number*	*Percent*	*1941*—Continued		
May 2	141	46.0		*Number*	*Percent*
3	113	26.5	April 21	114	20.2
4	103	20.4	22	167	23.4
6	116	9.5	23	84	17.9
7	118	6.8	25	267	12.5
8	40	5.0	26	82	15.8
10	11	0	28	125	28.8
11	56	0	29	10	20.0
15	49	0	30	139	7.2
			May 1	132	15.9
1941			4	42	19.0
April 18	40	12.5	7	65	15.4
19	105	17.1	8	93	23.7
20	127	21.3	9	90	25.6

The results for the 1941 season (table 4) do not show the adverse influence of environment which characterized the previous season. In 1941 conditions were generally more favorable for fruit setting, since no extreme fluctuations in temperature and soil moisture occurred. Furthermore, rainfall was well distributed over the period, being recorded as follows: 0.10 inch, April 25; 0.13 inch, April 26; 0.60 inch, April 29; 1.64 inches, April 30; and 0.31 inch, May 1. However, no rain fell after May 1 until May 24; the total precipitation for the month was 4.62 inches below normal. Most of the variations in fruiting during 1941 can be accounted for by differences in male and female parents used on the various dates of pollination.

As the temperature is generally high during May in Baton Rouge, it seems advisable to plant parental breeding material in the field early enough for pollination work to start by April 15 to 20. The results obtained on fruit set during the latter part of April and early May in 1941 indicate that ordinarily no trouble should be encountered in securing adequate seed supplies in Louisiana.

DISCUSSION AND SUMMARY

Results of the investigations on the prevalence of nonfruitfulness in potato varieties due to pollen sterility and premature abscission of flowers generally substantiate the reports of other workers in different

regions. However, the data do show that an encouraging number of fruitful varieties and seedling varieties possessing superior germ plasm are available to the potato breeder. Records on fruitfulness of varieties should have practical application in enabling the breeder to make more efficient use of the available material.

Isolation of potato flowers to prevent contamination with foreign pollen by enclosing the flower clusters in kraft-paper or cheesecloth bags was detrimental to fruit setting in Louisiana during the 1940 and 1941 seasons. The reduction in fruit set from the use of bags was apparently due in the main to alteration of temperature and humidity relations around the flowers. Of the two types of bags used, kraft-paper bags proved most satisfactory from the standpoint of time required in application. The results indicate that under reasonably favorable weather conditions adequate supplies of seed can be secured under kraft-paper bags in Louisiana.

Application of pollen at the time of emasculation of flowers (in the bud stage) was relatively ineffective in inducing fruit set in the Katahdin variety. Results with only one pollination 24 hours after emasculation indicate that this method was as efficacious as pollination simultaneously with emasculation, followed by a second pollination 24 hours later. In view of the results secured in this study, it would seem advisable to emasculate and bag potato flowers one day and apply pollen on the following day.

High temperature and low moisture or low moisture proved unfavorable to fruit setting in the potato. The results reported are in close accord with the findings of other investigators and demonstrate the marked sensitivity of fruiting in the potato to the environment. Environmental conditions favorable to general growth are apparently favorable to fruiting. Thus, it is advisable that, in conducting a potato-improvement program by breeding, the breeder should arrange to have the pollination work come during a period in which relatively low temperature and adequate soil moisture conditions normally prevail.

Natural cross-pollination in potatoes, although not investigated in the work herein reported, is undoubtedly possible, and it may occur to a small degree in unbagged flowers under field conditions in Louisiana. The extent of cross-pollination cannot be stated for any region with any degree of precision. The potato breeder should recognize this possibility of contamination with foreign pollen in conducting pollination work, and each worker must make the decision as to whether bagging of flowers, with consequent loss of time and labor and lower percentage of fruiting, is necessary or advisable to his program. It may be argued that the degree of crossing is so low as to be negligible in the ordinary breeding program, especially where no genetic interpretation is to be placed on the results. Nevertheless, in obtaining seed for use in genetic studies, isolation of flowers by some method of bagging would seem advisable.

LITERATURE CITED

(1) Clark, C. F.
1935. Report of research committee on potato breeding. Amer. Potato Jour. 12: 91–94.

(2) East, E. M.
1908. Technique of hybridizing the potato. Amer. Soc. Hort. Sci. Proc. 5 (1907): 35–40.

(3) KRANTZ, F. A., BECKER, C. L., and FINEMAN, Z. M.
1939. INCIDENCE AND INHERITANCE OF POLLEN STERILITY IN THE POTATO. Jour. Agr. Res. 58: 593–601.
(4) ——— and HUTCHINS, A. E.
1929. POTATO BREEDING METHODS. II. SELECTION IN INBRED LINES. Minn. Agr. Expt. Sta. Tech. Bul. 58, 23 pp., illus.
(5) LUNDEN, AKSEL P.
1937. INHERITANCE STUDIES IN THE POTATO (SOLANUM TUBEROSUM, L.). Norges Landbr. Høiskoles Årsmelding . . . om Åkervekstforsøk 46: 1–156. [In Norwegian. English summary, pp. 147–150.]
(6) SALAMAN, R. N.
1910. MALE STERILITY IN POTATOES, A DOMINANT MENDELIAN CHARACTER. Linn. Soc. London, Jour. Bot. 39: 301–312.
(7) STEVENSON, F. J., and CLARK, C. F.
1937. BREEDING AND GENETICS IN POTATO IMPROVEMENT. U. S. Dept. Agr. Yearbook 1937: 405–444, illus.
(8) STUART, W.
1937. THE POTATO: ITS CULTURE, USES, HISTORY AND CLASSIFICATION. Ed. 4, rev., 508 pp., illus. Chicago, Philadelphia, and New York.
(9) USPENSKII, E. M. [USPENSKY, E. M.]
1935. THE BIOLOGY OF POTATO BLOOMING. Raboty Nauch. Issled. Inst. Kartof. Khoz. (Physiol. Lab. Potato Sci. Res. Inst. Contrib.) No. 8, 152 pp., illus. [In Russian. English summary, pp. 144–152.]
(10) YOUNG, W. J.
1923. THE FORMATION AND DEGENERATION OF GERM CELLS IN THE POTATO. Amer. Jour. Bot. 10: 325–335, illus.

ISOLATION OF CERATOSTOMELLA ULMI FROM INSECTS ATTRACTED TO FELLED ELM TREES [1]

By T. H. JONES,[2] *senior entomologist, Division of Forest Insect Investigations, Bureau of Entomology and Plant Quarantine,* and C. S. MOSES, *assistant pathologist, Division of Forest Pathology, Bureau of Plant Industry, Agricultural Research Administration, United States Department of Agriculture*[3]

INTRODUCTION

The role of insects in the dissemination of *Ceratostomella ulmi* Buisman, the fungus that causes the Dutch elm disease, seems to be twofold. The insect contaminated with the fungus may feed directly on a living elm tree and thereby cause infection, or it may establish *C. ulmi* in dead or dying elm wood, whence its progeny or other insects may carry the fungus when they emerge. A knowledge of what insects are involved, and of their relative importance, is an essential part of the foundation upon which measures for the eradication and control of the disease must be based.

During the years 1936–39 insects were collected from recently felled elm trees at selected locations in New Jersey and New York. For the most part these insects were species known to breed in elms. They were later cultured to determine what species were carrying *Ceratostomella ulmi*, and to find the percentage of individuals of each species that were contaminated with the fungus. The results of this investigation are presented in this paper.

METHODS OF COLLECTING AND CULTURING INSECTS

The insects were taken from the surface of the bark of healthy American elms (*Ulmus americana* L.) that had been felled and placed horizontally on supports about 2 feet from the ground. They were collected individually in new gelatin capsules, care being taken to prevent contamination. The insects were sent by mail daily to the Morristown, N. J., laboratory, where they were identified without being removed from the capsules and refrigerated at 5° C. or lower temperatures until they were cultured.

The insects were cultured individually according to the following method, a modification of that described by Walter.[4] A Petri dish containing two pieces of filter paper and a chip from a small twig of seasoned elm was autoclaved for 20 minutes at 15 pounds' pressure and moistened with 4 cc. of sterile distilled water. The insect was then crushed on the chip with a sterile forceps, and the Petri dish was

[1] Received for publication February 25, 1942. The investigation reported was a cooperative one between the Dutch Elm Disease Eradication unit and the Division of Forest Insect Investigations of the Bureau of Entomology and Plant Quarantine, and the Division of Forest Pathology of the Bureau of Plant Industry. Members of the Dutch Elm Disease Eradication unit cut, placed, and later removed the elm trees from which the insects were collected, and employed men to collect and culture these insects.

[2] Died Feb. 22, 1941.

[3] The writers wish to acknowledge their indebtedness to those members of the three cooperating agencies who assisted in this work in various ways, especially the following members of the Bureau of Entomology and Plant Quarantine: To C. H. Hoffmann for determining many of the insects, to D. O. Wolfenbarger for assistance in supervising the field work in 1936, to R. R. Whitten for advice regarding the sampling method used in 1939, and to A. E. Lantz for preparing the figures that accompany this article.

[4] WALTER, J. M. TECHNIQUE ADVANTAGEOUS FOR THE ISOLATION OF CERATOSTOMELLA ULMI FROM BARK BEETLES. (Abstract) Phytopathology 25: 37–38. 1935.

incubated for about 20 days at 10° to 15° C. Since the typical fruiting structure of the imperfect stage of *Ceratostomella ulmi* is a coremium about 1,200 to 1,500μ in height, it is fairly conspicuous, especially when observed under a binocular dissecting microscope. Transfers were made from the coremial heads to malt or potato-sucrose agar plates with a sterile needle. Identification of *C. ulmi* was made by microscopic examination of the colonies produced by these transfers. This procedure was necessary because coremia-forming fungi other than *C. ulmi* were sometimes present in the cultures.

INVESTIGATIONS IN 1936

In 1936 three felled trees were installed on May 18 in sunny situa-

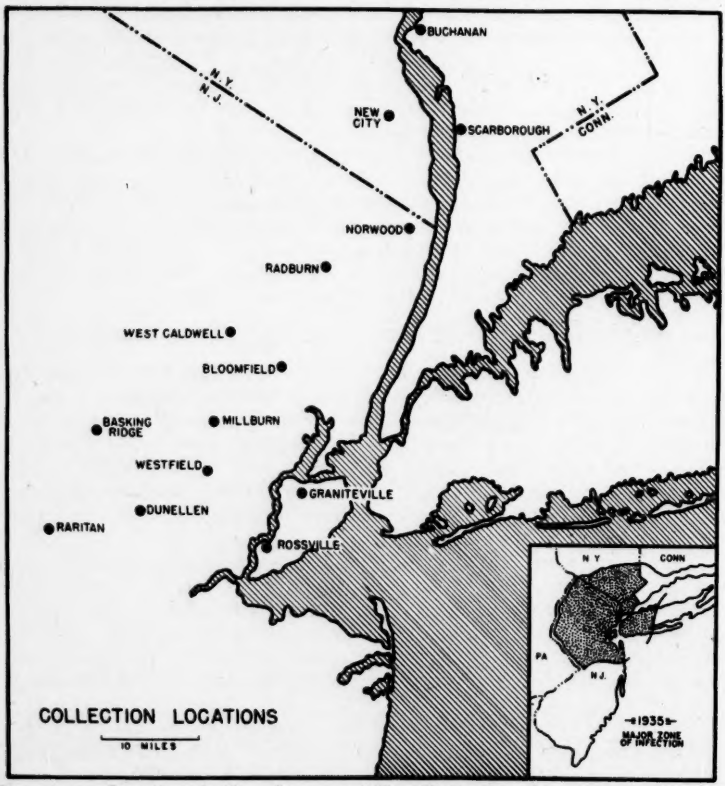

FIGURE 1.—Locations in New Jersey and New York where insects were collected. Insert shows major zone of Dutch elm disease infection as known in December 1935 and within which the insect collections were made.

tions at each of six places in New Jersey where elm trees affected by the Dutch elm disease had been removed previously in some numbers. These locations were in Basking Ridge, Westfield, Bloomfield, Radburn, Millburn, and West Caldwell (fig. 1). After 2 weeks one of the trees at each location was removed, burned, and replaced by a newly felled tree. This procedure was repeated every 2 weeks so that three

felled trees were exposed at all times at each location and no tree was left longer than 6 weeks.

A man was assigned to each location with instructions to collect all adults seen on the bark of the trees. It might be expected that numerous individuals of species having no intimate connection with elm would be taken, but as a matter of fact most of the insects taken were of species known or suspected to develop in elm, either by feeding in the wood and bark or as parasites and predators on insects breeding in elm.

The collectors worked at all locations from May 25 to September 9, and some of them for a few days before or after this period. Each man was on duty on week days from 8 a. m. to 4:30 p. m. (eastern daylight-saving time) and on Saturdays from 8 a. m. to noon, except that once each week his hours were from 4 p. m. to midnight. At night the men used electric lanterns to aid them in finding insects on the trap trees, but no trapping devices other than the felled trees were employed.

TABLE 1.—*Isolation of Ceratostomella ulmi from insects collected at six selected locations in New Jersey in 1936*

Insect	Insects cultured	Insects from which *C. ulmi* was isolated
	Number	*Percent*
Coleoptera:		
Scolytidae:		
Scolytus multistriatus (Marsh.)	7,209	6.9
Scolytus sulcatus Lec.	1	0
Hylurgopinus rufipes (Eich.)	139	4.3
Xylosandrus germanus Bldfd.	826	.2
Xyleborus sp.	25	0
Chramesus hicoriae Lec.	1	0
Other Scolytidae	1	0
Bostrichidae: *Xylobiops basilaris* (Say)	114	1.8
Cerambycidae:		
Saperda tridentata Oliv.	78	0
Neoclytus acuminatus (F.)	555	0
Xylotrechus colonus (F.)	39	0
Other Cerambycidae	2	0
Buprestidae:		
Chrysobothris femorata (Oliv.)	202	0
Anthaxia viridifrons Gory	83	0
Other Buprestidae	2	0
Curculionidae:		
Magdalis armicollis (Say)	1,419	.1
Magdalis barbita (Say)	338	0
Magdalis inconspicua Horn	474	0
Conotrachelus anaglypticus (Say)	143	.7
Other Curculionidae	2	0
Cleridae:		
Enoclerus quadriguttatus (Oliv.)	9	0
Chariessa pilosa (Forst.)	15	0
Other Cleridae	1	0
Histeridae:		
Platysoma coarctatum Lec.	3	0
Other Histeridae	2	0
Lampyridae	27	0
Nitidulidae: *Colopterus semitectus* (Say)	1	0
Corylophidae: *Molamba* sp.	1	0
Melandryidae: *Synchroa punctata* Newm.	9	0
Elateridae	37	0
Tenebrionidae	1	0
Chrysomelidae: *Microrhopala vittata* (F.)	4	0
Hymenoptera:		
Xiphydriidae: *Xiphydria* sp.	2	0
Braconidae: *Capitonius saperdae* (Ashm.)	5	0
Formicidae	58	0
Hemiptera:		
Membracidae:		
Stictocephala lutea (Walk.)	65	0
Other Membracidae	3	0
Pentatomidae: *Brochymena* sp.	1	0
Total	11,947	

The insects collected and cultured in 1936, as well as the percentages yielding *Ceratostomella ulmi*, are given in table 1. The species showing the highest percentage of infection were *Scolytus multistriatus* (Marsh.) and *Hylurgopinus rufipes* (Eich.), and the fungus was isolated from four other species. The numbers of *S. multistriatus* and *H. rufipes* collected at each of the six locations, and the percentages from which *C. ulmi* was obtained, are shown in table 2.

Figure 2 shows graphically how the numbers of *Scolytus multistriatus* taken during weekly collection periods at all locations, and the percentages of these beetles found to be contaminated with *Ceratostomella ulmi*, varied throughout the season. Only five beetles were collected during the May 24–31 and the September 13–19 periods in 1936, and it is on these limited numbers that the indicated 20 percent of contaminated beetles is based. The small number of *S. multistriatus* adults taken between July 12 and 25 is interpreted as being due to the fact that this period fell between the peaks of abundance of adults of the first and second generations.

The number of collected adults of the various species known to breed in elm cannot be used as a basis for estimating the comparative abundance of these species, even in the immediate vicinity of the trap trees. It is certain, for instance, that had the trees been installed earlier in 1936 and in the subsequent years in which the investigation was conducted, more *Hylurgopinus rufipes* would have been collected. Sixty percent of the insects collected were *Scolytus multistriatus*. This species is recognized as the most important insect vector of the Dutch elm disease fungus in this country.

Since the sex of *Scolytus multistriatus* adults can be determined readily, it was deemed advisable to ascertain whether a greater percentage of one sex than of the other was carrying the fungus. The sex was determined before the beetles were cultured. Males composed 71.2 percent of the total number, no doubt because the males run about more on the surface of the bark than do the females and were thus more often seen by the collectors. *Ceratostomella ulmi* was isolated from 6.9 percent of the males and from 7.1 percent of the females.

504160—43——3

TABLE 2.—*Isolation of Ceratostomella ulmi from Scolytus multistriatus and Hylurgopinus rufipes collected at selected locations in 1936, 1937, 1938, and 1939*

Location	From *Scolytus multistriatus*								From *Hylurgopinus rufipes*							
	Insects collected in—				Insects giving *C. ulmi* in—				Insects collected in—				Insects giving *C. ulmi* in—			
	1936	1937	1938	1939	1936	1937	1938	1939	1936	1937	1938	1939	1936	1937	1938	1939
New Jersey:	*Number*	*Number*	*Number*	*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*	*Number*	*Number*	*Number*	*Percent*	*Percent*	*Percent*	*Percent*
Basking Ridge	620	2,685	1,960	1,400	8.5	6.8	11.3	6.75±1.55	72	566	84	356	4.2	2.6	1.2	0.8
Westfield	1,551	1,625	8,940	9,357	6.9	5.4	12.7	1.75±0.66	0	1	144	107	0	0	4.2	0
Bloomfield	2,461	3,925	2,162	5,143	4.9	5.7	3.9	6.00±1.28	1	5	6	7	100.0	0	0	14.3
Radburn	497	542	5,281	1,020	3.0	.9	2.3	3.00±1.33	0	0	0	1	0	0	0	0
Millburn	1,414	972	6,339	3,517	9.5	5.7	8.7	9.25±1.41	11	6	15	51	0	0	0	0
West Caldwell	666	47	8,510	6,167	10.1	19.2	5.1	7.50±0.92	55	34	25	32	3.6	0	8.0	0
Total or average	7,209	9,796	33,192	26,604	6.9	5.8	7.7	5.71±2.51	139	612	274	554	4.3	2.4	3.3	.7
Norwood		410				2.9				0				0		
Raritan		2,321				5.1				43				2.3		
Dunellen		380				3.9				0				0		
New York:																
New City		280				3.2				63				1.6		
Scarborough		1,218				2.3				122				.8		
Buchanan		827				.8				65				0		
Rossville		351				.8				0				0		
Graniteville		2				0				0				0		
Grand total or average		15,585				4.8				905				2.0		

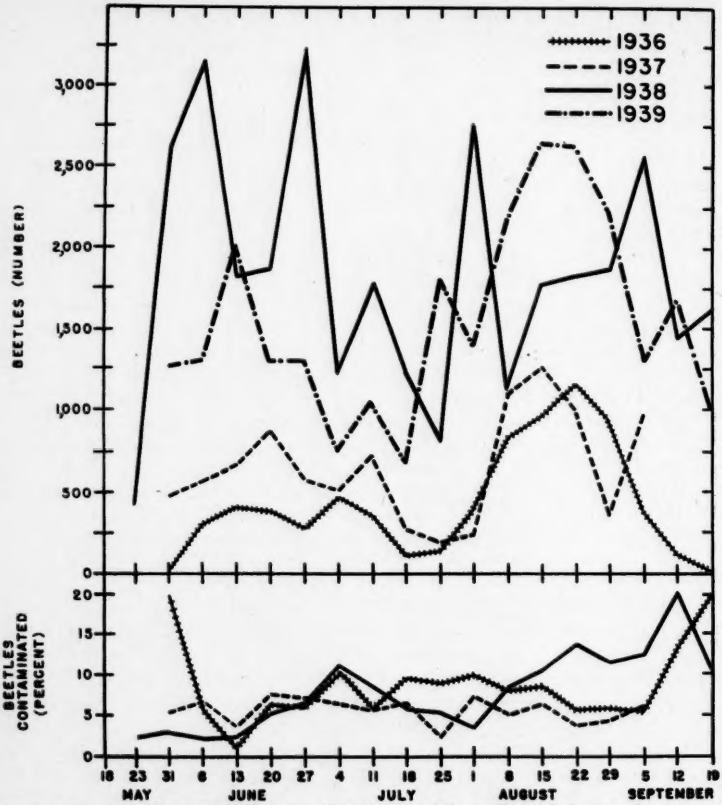

FIGURE 2.—Numbers of *Scolytus multistriatus* adults collected during the seasons of 1936–39, and the percentages of these beetles contaminated with *Ceratostomella ulmi* during the first 3 years. Collections from six locations in New Jersey have been combined for the periods indicated.

INVESTIGATIONS IN 1937

Freshly cut elm trees were installed on May 17, 1937, at the same places in New Jersey in which insect collections had been made during 1936. Trees were also installed at eight additional places—Norwood, Raritan, and Dunellen, N. J., New City, Scarborough, and Buchanan, N. Y., and Rossville and Graniteville on Staten Island, N. Y. (fig. 1). Four trees were placed at each location, three in a sunny situation and the fourth where it would be shaded most of the time. The trees in the sunny situation were later removed and replacements made as in 1936. The tree in the shady location was removed every 4 weeks and another put in its place.

Since in 1936 *Ceratostomella ulmi* was isolated more frequently from *Scolytus multistriatus* and *Hylurgopinus rufipes* than from the other species, and since these species are considered to be the most important

insect carriers of *C. ulmi* in the United States,[5] the collections of 1937 were limited to these two species.

The collectors began work on May 17, but they captured no bark beetles until May 24. At the six sites used in 1936 collecting was continued until September 5, but at the eight additional sites it was discontinued on July 14. The men were at each location on alternate days only, instead of daily as in 1936.

No night collecting was done in 1937. The men worked from 9 a. m. until 6 p. m., for it had been found in 1936 that 8 a. m. was early for insect activity and that activity continued after 4:30 p. m. Therefore, they probably captured more insects during any one day than had the hours been the same as in 1936. Because of this change in hours, because collections were made only on alternate days at any one place in 1937, and for other reasons the difference in numbers of *Scolytus multistriatus* or *Hylurgopinus rufipes* taken during the 2 years does not represent yearly fluctuations in abundance of either species.

The methods of identifying and culturing the insects in 1937 were similar to those in the previous year. The numbers of *Scolytus multistriatus* and *Hylurgopinus rufipes* taken at each location and the percentages of each yielding *Ceratostomella ulmi* are shown in table 2. As in 1936, *C. ulmi* was isolated from a higher percentage of *S. multistriatus* than of *H. rufipes*. The combined number of *S. multistriatus* taken at the six locations during approximately weekly periods and the percentages of these beetles from which *C. ulmi* was isolated are indicated in figure 2.

The sex ratio of *Scolytus multistriatus* approached that in 1936. In 1937, 76.6 percent of this species were males. *Ceratostomella ulmi* was isolated from 6.0 percent of the males and from 5.0 percent of the females.

INVESTIGATIONS IN 1938

In 1938 four trap trees were again put in place at each of the six sites used in 1936 and 1937. Three trees were again placed in a sunny situation and one in a shaded position. The schedule for removing the trees and replacing them by others was the same as in 1937. Collectors were at each location on alternate days from May 16 to September 17. Their hours were the same as in 1937, and they again collected only *Scolytus multistriatus* and *Hylurgopinus rufipes*.

Table 2 includes the numbers of the two species taken at each of the six locations, and the percentages of each from which *Ceratostomella ulmi* was obtained. Figure 2 indicates the combined number of *Scolytus multistriatus* taken at the six sites during intervals of approximately a week throughout the collecting season, and the percentages of these beetles from which *C. ulmi* was cultured. No separation of the sexes of *S. multistriatus* was made in 1938.

From figure 2 it will be noted that many more *Scolytus multistriatus* were collected in 1938 than in either of the 2 previous years, particularly in the early part of the season. The marked increase is believed to be due to the fact that numerous elms near four of the sites had been treated with dry copper sulfate late in 1936 or early in 1937. These elms were of small value, and the Dutch Elm Disease Eradica-

[5] MAY, C., and COLLINS, C. W. THE DUTCH ELM DISEASE IN THE UNITED STATES AND ITS INSECT VECTORS. West. Shade Tree Conf. Proc. 5: 49–54. 1938.

tion unit treated them with the chemical for the purpose of killing them and thus reducing the number to be inspected for external symptoms of the disease.[6] When the work was done it was not expected that bark beetles would attack these chemically treated trees. They did, however, and many of the *S. multistriatus* adults that were taken from the trap trees in 1938 may have originated in these trees. Conversely, it is also probable that the treated trees influenced the number of *S. multistriatus* collected from the trap trees in 1937, because the trees treated with copper sulfate were more attractive to the beetles than were the trap trees.

Figure 2 also indicates that a larger percentage of *Scolytus multistriatus* beetles collected during the latter part of 1938 were contaminated with *Ceratostomella ulmi* than of the beetles collected earlier. Most of these contaminated beetles were taken from one location, where the collections were comparatively large.

INVESTIGATIONS IN 1939

The procedure followed in installing the trap trees and collecting insects in 1939 was the same as that used in 1938. The collectors reported for duty on May 22 and worked until September 16.

It was impossible to culture all the *Scolytus multistriatus* beetles collected in 1939. Consequently, the capsules containing those beetles taken at each location were thoroughly mixed, and 20 samples of 20 beetles each were drawn at random and then cultured in the usual manner.[7] The culture results were analyzed statistically according to standard methods. Table 2 indicates the number collected at each location and the percentages from which the fungus was obtained.

Figure 2 shows the total number of *Scolytus multistriatus* taken at the six sites at intervals of approximately a week. Since the collections for the entire season were combined, it is impossible to show the weekly variation in the percentages of beetles carrying the fungus, as has been done for previous years.

All *Hylurgopinus rufipes* adults collected in 1939 were cultured. The number taken at each location and the percentages of each from which the fungus was obtained are given in table 2.

SUMMARY

Experiments were conducted from 1936 to 1939 to ascertain what species of insects were carrying the Dutch elm disease fungus (*Ceratostomella ulmi* Buisman) and from what percentage of each of these species the organism could be isolated. Insects attracted to felled healthy elm trees placed at several locations in New Jersey and New York were collected, identified, and cultured.

In 1936 all adult insects found on the surface of the bark of felled elms at six sites in New Jersey were collected and cultured. They included identified individuals of 23 species and many other specimens that were determined only to family or genus. *Ceratostomella ulmi* was isolated most frequently from two species of elm bark beetles, *Scolytus multistriatus* (Marsh.) and *Hylurgopinus rufipes* (Eich.). It was also isolated from four other species of Coleoptera, namely,

[6] BREWER, E. G., and MIDDLETON, W. DUTCH ELM DISEASE ERADICATION; JAPANESE BEETLE CONTROL; EUROPEAN CORN BORER AND GYPSY MOTH CERTIFICATION. Jour. Econ. Ent. 31: 577–583. 1938.

[7] In 1939, all the culture work was done under the supervision of L. M. Fenner and E. G. Kelsheimer, of the Bureau of Entomology and Plant Quarantine.

Xylobiops basilaris (Say), *Conotrachelus anaglypticus* (Say), *Xylosandrus germanus* Bldfd., and *Magdalis armicollis* (Say).

Because of the results of the 1936 experiment, and because *Scolytus multistriatus* and *Hylurgopinus rufipes* are considered the most important insect vectors of *Ceratostomella ulmi* in the United States, only adults of these two species were cultured in 1937, 1938, and 1939. They were collected at the same six locations as in 1936 Many more *S. multistriatus* than *H. rufipes* were taken. *C. ulmi* was obtained from 6.9, 5.8, 7.7, and 5.71 percent of the *S. multistriatus*, and from 4.3, 2.4, 3.3, and 0.7 percent of the *H. rufipes*, cultured in 1936, 1937, 1938, and 1939, respectively. The percentage of beetles contaminated with *Ceratostomella ulmi* varied considerably at different locations in the same year and at the same location in different years. In 1937 *Scolytus multistriatus* and *H. rufipes* collected at eight additional locations in New Jersey and New York were cultured.

In 1936 and 1937 the sex of the *Scolytus multistriatus* adults was determined before they were cultured. Males composed 71.2 percent of the adults in 1936 and 76.6 percent in 1937. In 1936 *Ceratostomella ulmi* was cultured from 6.9 percent of the males and from 7.1 percent of the females; in 1937 the percentages were 6.0 and 5.0, respectively.

DEPOSITS OF INSECTICIDAL DUSTS AND DILUENTS ON CHARGED PLATES [1]

By G. F. MacLeod, *entomologist*, and Leslie M. Smith, *assistant entomologist, Division of Entomology and Parasitology, California Agricultural Experiment Station*[2]

INTRODUCTION

Preliminary tests on avocado leaves directed attention to the importance of the relation of frictional charges on dust particles to the deposition and adhesion of insecticides. A review of the literature showed that the physical influence of diluents upon the insecticidal action of the active principle in dust mixtures had not received the attention that it merits.

The possible interrelations of some physical factors that affect the insecticidal action of a dust are set forth in the flow chart shown in figure 1. Aside from chemical toxicity, the insecticidal action of a dust will depend primarily upon deposition, i. e., putting the powder on the plant or insect; and adhesion, i. e., the ability of the powder to remain in place under weathering influences. Deposition may be dependent upon elutriation, i. e., separation by differential flotation, and upon frictional charge, i. e., an accumulation of static charges caused by the dust striking against other materials while being blown to the plants. Elutriation is obviously controlled by particle size and particle density, provided complete deflocculation is assumed. Since, however, in commercial dusting practice many aggregates are present in the dust cloud, those factors that contribute to the formation of aggregations are indirect factors influencing elutriation. Some such factors are moisture content, frictional charge, particle size, and cohesion. Frictional charge may be influenced by the moisture content of the dust, by climatic conditions, by the dusting machine, and, in the case of a mixture of two or more powders, by friction between unlike particles. Some of the factors which influence the development of a frictional charge on insecticidal powders as well as some of the possible effects of such a charge on the behavior of the dust are given in the flow chart in figure 2.

EQUIPMENT AND METHODS

An attempt has been made to measure the effect of several factors on deposition, adhesion, elutriation, and formation of aggregations. For this purpose, an apparatus was devised (fig. 3) consisting of a Niagara rotary hand duster, a copper-lined sedimentation chamber, and two copper plates which, when charged, maintained an electrostatic field between them. The feeder opening on the duster was calibrated in

[1] Received for publication June 4, 1942. Assistance was rendered by the Work Projects Administration through Project O. P. 465-03-3-168.

[2] The authors gratefully acknowledge the patient and careful criticisms of this work received from Dr. Leonard B. Loeb, professor of physics at the University of California.

eighths of the total area. Metal outlet tubing was either the standard Niagara galvanized-iron tubing or galvanized-iron drain pipe. The rubber tubing used was radiator hose, garden hose, and compressed-air coupling hose such as are used on freight cars.

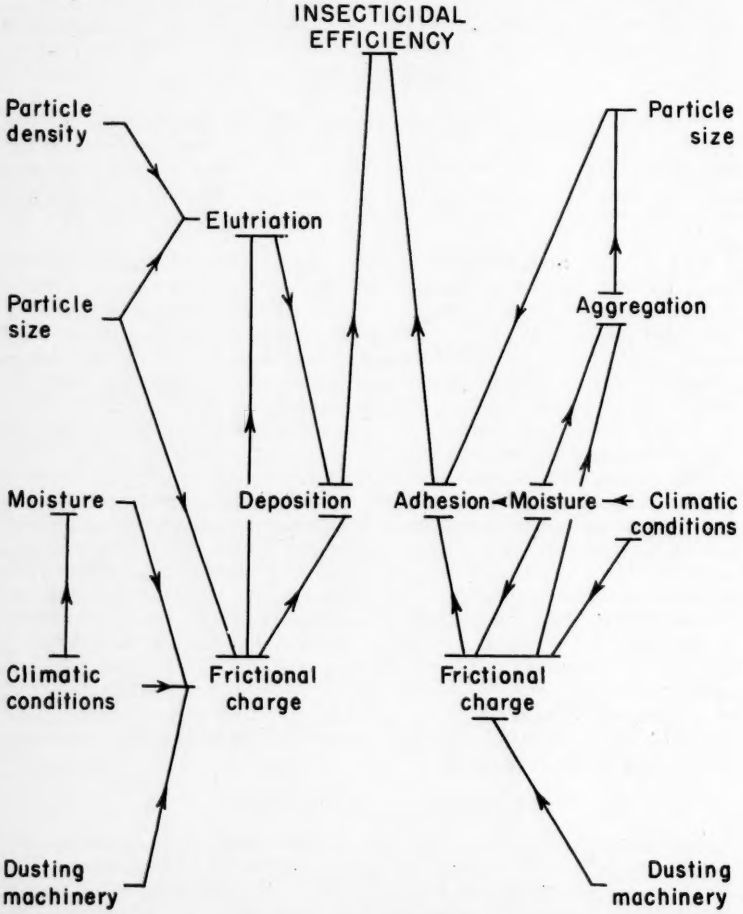

FIGURE 1.—Flow chart showing possible interrelations of some physical factors influencing the insecticidal action of the active ingredient in a dust mixture.

The sedimentation chamber, 50 inches long, provided a space in which the larger particles, lumps, and aggregations dropped out of the air stream. If these large masses were blown across the charged plates they swept off the deposit of charged material, thereby introducing an error.

The charged plates, 12 inches square, were shellacked on their inner faces. They were symmetrically arranged on a vertical plane, ½ inch

apart at the top and ¾ inch apart at the bottom, so that no dust could fall onto them from above or be held there by gravity. The usual working potential on the plates was 500 volts, direct current (supplied from a rectifying tube on 110-volt alternating current with a fluctuation of about 2 volts. For certain studies the voltage was controlled between 200 and 500 volts by means of two variable resistances.

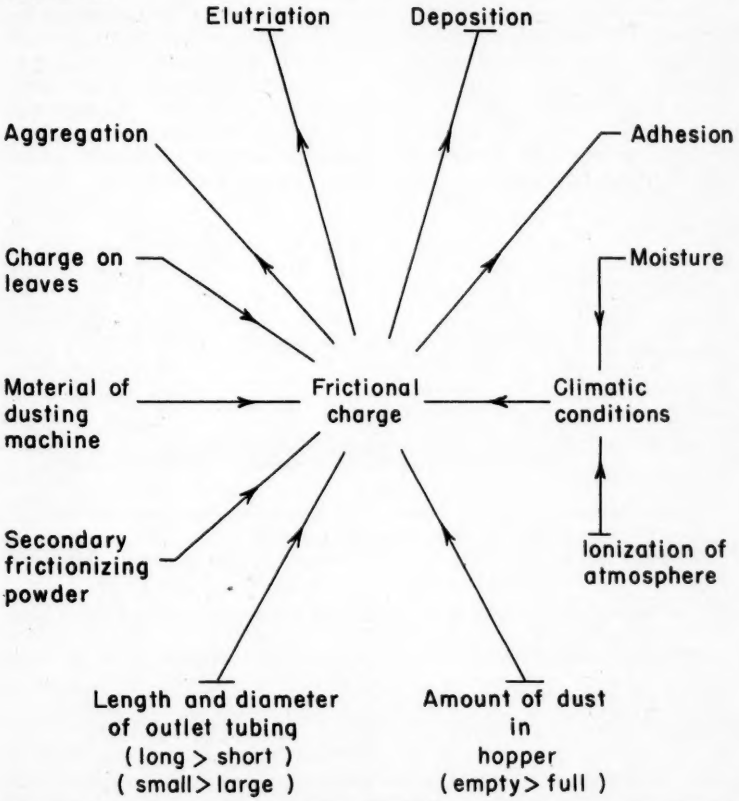

FIGURE 2.—Flow chart showing some of the factors which influence development of a frictional charge on insecticidal powders as well as some of the possible effects of such a charge on the behavior of the dust.

In operation, the crank of the duster was turned by hand at a relatively uniform, slow speed until a significant weight of dust was judged to have adhered to the plates. The hinged plates were then opened downward like a book, and the deposit on each plate removed over the area covered by a single swath of a 10-inch rubber squeegee. The dust removed from each plate was weighed.

In all cases care was taken by means of adequate control experiments to make sure that the deposit of dust was never too thick to interfere with proper deposition. The allowable density of deposit

for proper deposition varied with various dust samples and all data were taken within the allowable limits. To eliminate any effects of asymmetry in the apparatus or air stream measurements of successive runs were made by reversing the polarity of the plates and averaging the two runs.

EXPERIMENTAL RESULTS AND DISCUSSION

Since a large portion of any dust is not deposited on the plates but is blown out beyond, the question arose as to how this material would be deposited on charged plates. To answer this question, the apparatus was equipped with electrodes 12 inches high and 4 feet long. These longer plates collected practically all of the dust. Comparable and opposite areas 12 inches wide were laid off along these plates, and the percentage of material deposited on each plate was determined as shown in table 1. The major deposit was computed as per-

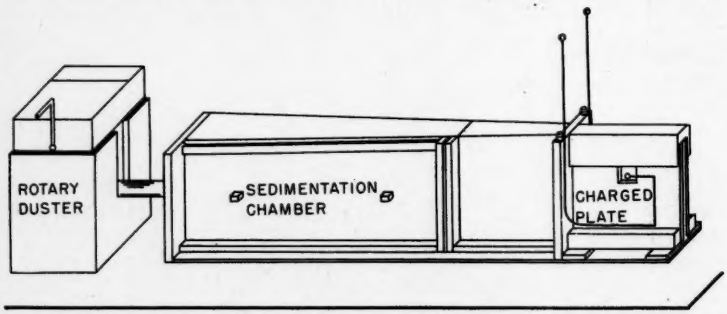

FIGURE 3.—Apparatus devised for measuring the effect of several factors on the deposition, adhesion, elutriation, and formation of aggregations in insecticidal dusts.

cent of the total deposit on both plates. The weighted averages were computed by the formula $\frac{T'P'+T''P''+\text{etc.}}{\Sigma T}$, wherein T is the total weight of dust collected at a given mean distance along the plates and P is the percentage of the major deposit composing that weight of dust.

TABLE 1.—*Deposits of dusts at various points on 4-foot electrodes*

Powder	Mean distance along plates	Total weight of dust collected	Major deposit	Weighted averages major deposit
	Inches	*Milligrams*	*Percent*	*Percent*
Soapstone No. 1	10	595	77.0	73.3
	25	364	72.1	
	39	302	67.5	
Rotenone dust No. 1	10	100	75.9	72.7
	25	147	70.0	
	39	120	70.5	

In all the data hereafter presented, the ratio of material (heavier deposit: total deposit) has been determined on electrodes 12 inches square placed at a distance comparable to the 10-inch mean distance

indicated in table 1, and for relative conclusions these data probably suffice. The true ratio for all the dust blown from the duster, however, may be somewhat lower (table 1).

The deposits which were obtained when several insecticidal powders and common diluents were blown through the apparatus described above with 20 inches of galvanized-iron outlet tubing on the duster, are given in table 2.

TABLE 2.—*Ratios of dust deposit when 20 inches of galvanized-iron outlet tubing was used on the duster*

Material	Charge on plate	Proportion of total deposit	Material	Charge on plate	Proportion of total deposit
		Percent			*Percent*
Redwood flour No. 1	Negative	93.4	Magnesium carbonate No. 1	Negative	57.8
Lead arsenate No. 2	do	89.2	Sulfur No. 10	do	57.6
Calcium arsenate No. 1	do	86.3	Sulfur No. 12	do	50.8
Calcium carbonate No. 1	do	86.2	Sulfur No. 2	Positive	51.6
Lead arsenate No. 1	do	80.6	Clay No. 2	do	56.9
Rotenone powder No. 1	do	80.3	Cryolite No. 1	do	58.5
Pyrethrum No. 1	do	80.0	Sulfur No. 14	do	60.7
Phenothiazine No. 1	do	76.9	Sodium fluosilicate No. 1	do	61.4
Dextrin No. 1	do	73.8	Soapstone No. 1	do	68.5
Calcium hydroxide No. 1	do	72.9	Talc No. 1	do	71.2
Calcium carbonate No. 3	do	71.2	Copper cyanide No. 2	do	79.9
Walnut-shell powder No. 2	do	70.4	Diatomite No. 2	do	80.5
Magnesium oxide No. 1	do	70.0	Diatomite No. 1	do	81.2
Rotenone powder No. 2	do	68.5	Sulfur No. 3	do	81.3
Barium fluosilicate No. 1	do	67.0	Calcium carbonate No. 2	do	81.5
Redwood bark No. 1	do	64.8	Clay No. 1	do	83.6
Sulfur No. 1	do	61.2	Bentonite clay No. 2	do	92.3
Gypsum No. 1	do	59.2	Bentonite clay No. 1	do	93.4

All the powders listed in table 2 were used in the form supplied to the insecticide trade; e. g., rotenone dusts were undiluted cube and derris powders, and the pyrethrum, fluosilicate, arsenate, etc., powders were also used undiluted. The several sulfur dusts were commercial brands which contained so-called conditioners.

The ratio of the deposits varied widely with variations in the dusting apparatus, with variations in the dust, and possibly with variations in the atmosphere. Several powders were blown through the sedimentation chamber and then between the charged plates by holding a pile of dust on a large spatula in front of the air blast from the rotary duster at the entrance to the sedimentation chamber. These dusts did not come in contact with the duster or the outlet tubing. The results are given in table 3.

TABLE 3.—*Deposits occurring when dust was blown from in front of outlet tube*

Material	Charge on plate	Proportion of total deposit	Gain or loss over deposit of dust blown through metal outlet tube (table 2)
		Percent	*Percent*
Calcium arsenate No. 1	Negative	78.0	−8.3
Barium fluosilicate No. 1	do	65.4	−1.6
Bentonite clay No. 1	Positive	90.3	−3.1
Diatomite No. 2	do	70.5	−10.0
Redwood flour No. 1	Negative	69.3	−24.3
Rotenone powder No. 1	do	68.4	−11.9
Soapstone No. 1	Positive	74.6	+6.1
Walnut-shell powder No. 2	Negative	80.1	+9.7

A 20-inch tube of brown wrapping paper was substituted on the duster for the 20-inch iron tube used in the first tests reported in table 2. Several powders were blown through such paper tubing with the results shown in table 4.

TABLE 4.—*Deposit occurring when 20 inches of paper outlet tubing was used*

Material	Charge on plate	Proportion of total deposit	Gain or loss over deposit of dust blown through metal outlet tube (table 2)
		Percent	*Percent*
Rotenone powder No. 2	Negative	63.2	−5.3
Rotenone powder No. 1	do	65.0	−15.3
Bentonite clay No. 1	Positive	90.9	−2.5
Redwood bark No. 1	do	69.8	+34.6
Redwood flour No. 1	do	52.4	+90.0
Cryolite No. 1	do	81.8	+23.3

The influence of the length of the outlet tubing on the ratio of deposits was tested by blowing several powders through iron or paper tubes of various lengths attached to the duster. The results are given in table 5 and shown graphically in figure 4.

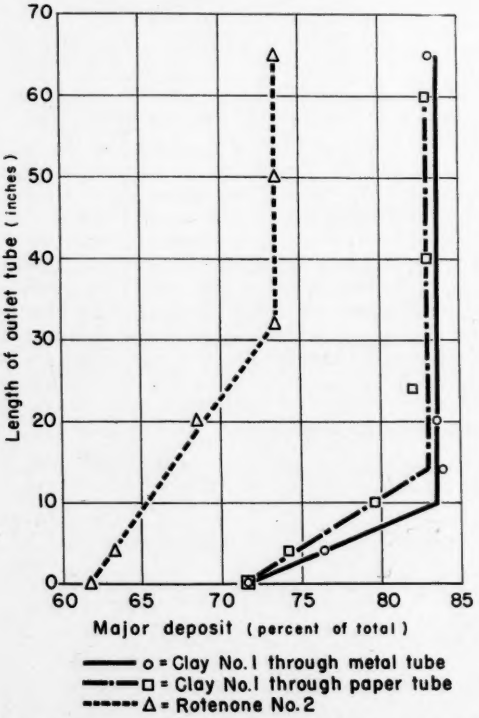

FIGURE 4.—The influence of the length of the outlet tubing on the ratio of dust deposits.

TABLE 5.—*Relation of the length of outlet tubing to ratio of deposits of dusts on electrodes*

METAL TUBING

Material	Tube length	Charge on plate	Proportion of total deposit
	Inches		*Percent*
Clay No. 1	0	Positive	71.6
	4	do	76.3
	14	do	83.9
	20	do	83.6
	65	do	83.2
Rotenone powder No. 2	0	Negative	61.8
	4	do	63.4
	20	do	68.5
	32	do	73.4
	50	do	73.5
	65	do	73.4
Talc No. 2	0	Positive	77.0
	5	do	80.0
	60	do	83.4

PAPER TUBING

Clay No. 1	0	Positive	71.6
	4	do	74.2
	10	do	79.6
	24	do	82.0
	40	do	83.0
	60	do	83.0

Lengthening the outlet tubing caused an increase in the major deposit until a maximum was reached. In the case of clay No. 1 the rate of increase of deposit was less for paper tubing than for metal tubing, although both types were of the same diameter. The maximum percentage of deposit in each case, however, was approximately the same. It is not known whether the increased deposit arises as a result of friction with the walls of the outlet tube, or by a redistribution of charges from particle to particle, or both.

The diameter of the outlet tubing and the presence of a coating of material probably affect the amount of deposit, as was indicated by the fact that whenever the outlet tube became partly clogged with powder, the major deposit was considerably reduced. For example, when the 20-inch iron outlet tube was allowed to become about half filled throughout its length with talc No. 2, the percentage of dust deposited on the positive plate dropped from 80.0 to 56.0 percent.

The size of the feeder opening also affects the ratio of deposits obtained, assuming that the air stream is held constant. The feeder opening on the duster was graduated in eighths and the deposit at each setting was determined. Precautions were taken to turn the crank at a uniform rate. The deposits shown in table 6 were obtained with bentonite clay No. 3 and 12 inches of iron outlet tubing was used.

TABLE 6.—*Variation in dust deposit with different feeder openings*

Feeder setting	Proportion of total deposit on positively charged plate	Feeder setting	Proportion of total deposit on positively charged plate
	Percent		*Percent*
One-eighth open	92.7	Five-eighths open	64.3
One-fourth open	80.9	Three-fourths open	64.2
Three-eighths open	78.2	Seven-eighths open	62.3
One-half open	64.1	Entirely open	60.1

In commercial dusting, powders are seldom used singly, dusting materials usually being compounded in mixtures of two, or occasionally three, powders. Consequently, the question arises as to the effect on the ratio of deposits when two powders are blown from the duster simultaneously and there is opportunity for friction between the particles of unlike powders. Four mixtures of two powders each were tested and the results are given in table 7.

TABLE 7.—*Deposits obtained when mixtures of two powders were tested*

Mixture	Charge on plate	Proportion of clay	Proportion of total deposit
		Percent	*Percent*
Bentonite clay No. 2 and redwood flour No. 1	Negative	0	94
	do	1	87
	do	5	70
	do	14	50
	Positive	25	60
	do	31	63
	do	35	70
	do	55	80
	do	57	83
	do	62	84
	do	86	89
	do	95	91
	do	99	95
	do	100	92
		Talc	
Talc No. 1 and walnut-shell flour No. 2	Negative	0	70
	do	1	86
	do	5	76
	Positive	50	54
	do	95	63
	do	99	68
	do	100	71
		Calcium carbonate	
Calcium carbonate No. 4 and diatomite No. 2	do	0	81
	do	1	81
	do	5	72
	do	50	70
	do	95	60
	do	99	55
	do	99.8	55
	Negative	100	53
		Walnut-shell flour	
Bentonite clay No. 1 and walnut-shell flour No. 2	Positive	0	93
	do	1	53
	do	5	68
	Negative	50	58
	do	95	62
	do	99	72
	do	100	70

Two noteworthy points are brought out in this test. In four out of eight cases the incorporation of 1 percent of another powder increased the deposit of the major component. Furthermore, the deposit which will be obtained with a mixture of two powders cannot be predicted from the behavior of each component studied separately (tables 2 and 7).

SUMMARY

To study deposits of commonly used insecticidal dusts and diluents a device was constructed with which the deposits of materials on positively and negatively charged plates could be measured. As a result of these tests it has been shown that:

In general, powders of plant origin gave heavy deposits on the negatively charged plate.

Diatomites and clays gave heavy deposits on the positively charged plate.

All other materials were variously distributed, a feature which was apparently influenced by the composition of the particular dust.

The material of which the outlet tube was constructed influenced the ratio of the deposits on the negative and positive plates.

An increase in the length of outlet tubing increased the major deposit of any given material up to a maximum point beyond which no further increase or decrease was apparent.

As the feeder opening was increased the major deposit of bentonite clay No. 3 decreased.

The addition of 1 percent of one powder to another increased the major deposit in four out of eight cases studied.

The deposit that would result from a mixture of two powders could not be predicted from a study of each of the component materials.

U. S. GOVERNMENT PRINTING OFFICE: 1943